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ACCOUNTING FOR SUBSISTENCE VARIATION AMONG MAIZE FARMERS IN OHIO VALLEY PREHISTORY

by

Diana Mae Greenlee

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

Doctor of Philosophy

University of Washington

2002

Program Authorized to Offer Degree: Anthropology

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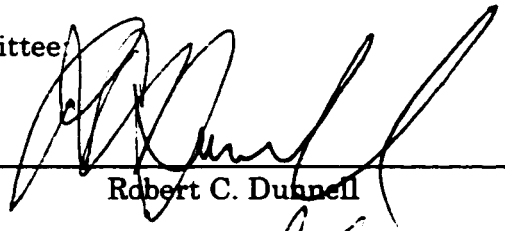
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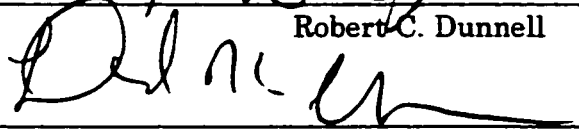


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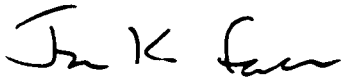
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Abstract

ACCOUNTING FOR SUBSISTENCE VARIATION AMONG MAIZE FARMERS IN OHIO VALLEY PREHISTORY

by Diana Mae Greenlee

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Four different causes (climatic change, demographic structure, resource availability and technology, and social context) have been suggested to account for aspects of the appearance of and variation in maize-based farming systems of the Eastern, but they remain undeveloped and, for the most part, unevaluated. Here, I examine variation in maize-based subsistence systems among populations of the middle and upper Ohio River valleys from the perspective of evolutionary theory. The four previously-espoused potential causes are rephrased as falsifiable hypotheses with evolutionary implications and are evaluated with respect to the archaeological record. Stable carbon isotope analyses of collagen derived from archaeological human skeletal remains, a measure of individual maize consumption, provide the backbone of this research. These bone chemistry data are then integrated with traditional sorts of archaeological data (e.g., botanical and faunal remains, environmental conditions, paleopathologies, settlement structure) to test each of the hypothesized causes for subsistence variation. Although data to thoroughly evaluate each of the hypotheses are unevenly available (the scarcity of crucial Late Woodland samples is particularly troublesome in all cases), a rough account of how and why maize farming in the study region varied as it did is produced. It is clear that no single parameter can account for the entire record of

subsistence variation. Explanations must be crafted by taking into account the particular circumstances of subsistence systems at specific places. Although future research is required to resolve the several questions that remain, the structure for doing so scientifically is now established.

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PREFACE

It has been said that the worldwide contemporary human food web is based on ten plants (Schultes 1988). Of those, maize has recently become the cereal with the highest worldwide annual production. According to the statistical databases[1] of the Food and Agriculture Organization (FAO) of the United Nations, in each of the past two years (1998-1999), more than 600 million tons of maize were produced on nearly 140 million hectares of land. Maize's role as the highest-producing cereal crop is a testament to its high average yield under varying environmental circumstances and its suitability for multiple uses (Dowswell et al. 1996). That maize production is a global phenomenon is supported by the fact that 44 countries each contributed more than one million tons of maize to the total crop in 1999 (FAO, see Footnote 1). Privately- and publicly-funded research programs are working to increase levels of maize production (expansion into unfavorable areas, increasing yields, decreasing costs), particularly in developing countries; these programs seek to both improve crop management practices and to develop disease- and insect-resistant, cold- and drought-tolerant, more efficient and nutritious genotypes while maintaining genetic diversity through germplasm banks (Dowswell et al. 1996; King and Dudley 1992; Malakoff 2000).

Maize contributes to the human foodweb both directly as human food and indirectly as animal feed; industrial products (e.g., corn starch, sweeteners, ethanol fuel, alcoholic beverages) also use a small proportion of the total yearly maize harvest. About 17% of the 1997 world maize crop (the most recent year with available data [see Footnote 1]) was consumed directly by people, roughly 67% was fed to livestock, about 9% was used in industrial processing, and the rest was kept

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[1] These and other data are available on the FAO's web site (www.fao.org) at http://apps.fao.org/.

for seed, went to waste, or was involved in other unspecified uses. The FAO's data on the direct contributions of maize to the total daily human diet indicate that it plays a widely varying role in contemporary subsistence systems. In 1997, maize supplied over 25% of the total direct caloric intake for the people of more than one dozen countries; of those, the people of three countries (Lesotho, Malawi, and Zambia) depended on maize for more than 50% of their dietary calories. At the same time, maize contributed less than 0.1% of the daily caloric intake for more than 15 countries. That there is significant geographic variation in the role played by maize in contemporary subsistence systems is also supported by analyses of the stable carbon isotopic compositions of food and hair from various populations (Nakamura et al. 1982).

How do we account for this subsistence variation and, more importantly, as we move toward a global system, what are the potential impacts of reliance on such a crop? Most of the current variation in subsistence systems around the globe likely results from a combination of cultural traditions, economics, crop characteristics and environmental conditions (Heiser 1990; McNeill 1991). These same factors were likely important in determining the contribution of maize to past systems and will likely be relevant to future systems. Although dispersing maize production over a range of ecological situations and maintaining genetic diversity both serve to reduce the likelihood of a global catastrophe, with such large proportions of human and animal populations dependent on the yearly maize crop, a bad year could still be disastrous for millions of people, particularly those whose own crops failed and who cannot afford to purchase food.

On an individual level, we know that adults whose diets are centered on maize may develop pellagra, a disease resulting from niacin deficiency and/or imbalances in three essential amino acids: tryptophan, leucine and isoleucine (Gontzea and Sutzescu 1968; Srikantia 1982a). Symptoms of pellagra include weakness, dermatitis, gastro-intestinal difficulties, an altered mental state

(insomnia, memory loss, depression, disorientation, paranoia) and perhaps death. There are several known ways to eliminate pellagra (e.g., diversifying the diet, consuming adequate amounts of animal protein, alkali-processing maize, enriching foods with niacin or providing niacin supplements, growing/consuming more nutritious varieties of maize), and their implementation has successfully eradicated pellagra in the developed countries. However, little headway has been made in controlling the incidence of pellagra in developing countries outside the Americas where maize is the dietary staple.

Children raised on a cereal-based diet often suffer from protein-energy malnutrition (PEM) and this is a widespread problem in developing countries (Poleman 1997; Srikantia 1982b). The protein:calorie ratio in maize is inadequate for meeting the nutritional requirements of children (Heiser 1990). In its milder forms, PEM produces stunted growth, increased susceptibility to infectious diseases and longer recovery times from those diseases. Indeed the synergistic relationship of disease and nutrition can make the consequences of PEM all the more grim. Both kwashiorkor and marasmus are considered to be severe forms of PEM that can lead to diminished mental capacity and death. PEM is also known to inhibit absorption of some vitamins, leading to dietary deficiencies in those nutrients even when they are available in adequate amounts, that can have serious health consequences (e.g., Vitamin A deficiency results in blindness). Although with treatment (providing balanced diets and controlling secondary infections) children can and do survive even extremely severe cases of PEM, they may suffer from permanent physical and mental damage.

Populations are growing in those countries that depend on maize for a significant proportion of their daily calories in spite of poor health and death associated with chronic malnutrition. In many of those places, the level of dietary reliance on maize is increasing. Presumably, that can only lead to more problems. There is little information available on the long-term viability of maize-based

subsistence systems. We can speculate that, with increased pressure on the maize crop, techniques that are known to enhance sustainability (e.g., fallow periods, mixed cropping, fertilization, terracing) will remain luxuries that subsistence farmers trying to feed their families over the short term cannot afford. With larger populations, less land per capita will be available for farming and it will be used more intensively; farming may expand into lands that are not well-suited to such uses. As soil fertility decreases, yields will decrease and a negative feedback loop will spiral toward subsistence disaster. The impact of pests, diseases, and/or climatic variation on these increasingly unstable subsistence systems may make episodes of famine more common. Although food aid from foreign sources may help mitigate specific crises, a long-term solution is required.

Subsistence problems, and indeed many of the environmental problems we face today, are not unique to contemporary politics, economics, or technology. From a historical perspective, "...the contemporary political and economic situation [is] the end product of thousands of years of a ... changing, fundamentally similar set of human-environmental interactions" (Redman 1999:xiii). Although the scale of our problems may be greater due to both larger population size and increased technological sophistication, the issues are much the same as those faced by past populations. If one accepts this position, then turning to the archaeological record can be invaluable because of its potential to "...enlarge the perspective and broaden the sources of data used for understanding the issues that confront us, in order for us to make better decisions for the future" (Redman 1999:xiii).

Here, I present a case-study, examining the historical trajectory of prehistoric maize farmers in the middle and upper Ohio River valleys of eastern North America. Although attempts to estimate the caloric contribution of maize to the diets in these populations are premature at best, it is clear that maize was *the* primary dietary staple in their subsistence systems. The goal is to determine how

and why specialized maize-based farming systems appeared when and where they did, why they varied as they did, and what the impacts of dietary reliance on maize were for those populations. From this examination, I hope to determine what parameters are relevant to understanding the implications of our dependence on maize in contemporary foodwebs.

ACKNOWLEDGMENTS

The author wishes to express sincere appreciation to the many institutions and individuals who assisted with this research. Access to archaeological skeletal remains was granted by many institutions (Carnegie Museum of Natural History, Cincinnati Museum of Natural History, Cleveland Museum of Natural History, Glenn Black Laboratory of Archaeology at Indiana University, Licking County Archaeology and Landmarks Society, Marshall University, Ohio Historical Society, University of Cincinnati, University of Kentucky Museum of Anthropology, University of Louisville, and U.S. Army Corps of Engineers [Huntington District]) and several individuals provided counsel regarding skeletal materials of potential interest (D. Brose, C. W. Cowan, W. Dancey, N. Freidin, R. Hawkins, W. Johnston, N. Justice, R. Kelly, R. Maslowski, M. Otto, M. Lucas Powell, P. Sciulli, and P. Tench).

I also want to thank the individuals who provided invaluable advice and access to equipment necessary for my analyses: M. Stuiver, P. Reimer, T. Saling and P. Wilkinson of the Quaternary Isotope Laboratory at the University of Washington assisted with generating the stable carbon isotope data and by providing a high-precision radiocarbon date; L. and N. Ericsson of AAA Laboratory assisted with amino acid analysis; J. Froseth and C. Hostetler of the Swine Teaching and Research Center at Washington State University helped with the formulation of the experimental pig diet, with raising the pigs and with acquiring relevant samples; K. Krogslund and J. Postel of the Marine Chemistry Laboratory in the Department of Oceanography at the University of Washington assisted with CHN analyses; S. Kuehner of the Electron Microprobe Laboratory in the Department of Earth and Space Sciences at the University of Washington helped with microprobe analyses; and L. H. Ericsson and K. Walsh of the Department of

Biochemistry at the University of Washington helped with the amino acid analyses and the ultrafiltration extraction protocol. J. Broughton's assistance in gaining access to a dermestid beetle colony for cleaning the pig bones is much appreciated. R. A. Bryson of the Center for Climatic Research at the University of Wisconsin, Madison generously provided preliminary climatic data for two Ohio sites derived from his macrophysical climatic models.

I also wish to acknowledge financial support received from several sources: the Anthropology Department, University of Washington; the Alice B. Niles and Genevieve D. Niles Graduate Fellowship; a National Science Foundation Graduate Fellowship; a National Science Foundation Dissertation Improvement Grant (SBR-9310137); a University of Washington Graduate School Dissertation Award; and the Carnegie Museum of Natural History (through P. Sciulli).

The members of my Ph.D. supervisory committee (E. Do, R. C. Dunnell, L. H. Ericsson, D. K. Grayson, J. K. Feathers, J. K. Stein, M. Stuiver and M. Tsukada) provided invaluable advice and criticism. Comments by my reading committee (R. C. Dunnell, D. K. Grayson and J. K. Feathers) greatly improved this effort. M. D. Dunnell and J. L. Libby also provided valuable editorial assistance. I am greatly indebted to my committee chair, R. C. Dunnell, who was especially generous with his time, expertise and patience. Finally, I want to acknowledge the advice, stimulating discussion, assistance and/or moral support provided by my graduate colleagues, especially F. Hamilton, M. King, K. Kornbacher, A. Linse, P. McCutcheon, L. Nagaoka, P. Reimer, and S. Sterling.

To all of these people and institutions and any omitted inadvertantly, I extend my sincere gratitude.

DEDICATION

The author wishes to dedicate this dissertation to

Jack L. and Grant T. Libby.

Thanks, you guys!

CHAPTER ONE: INTRODUCTION

The evolution of farming systems[2] and their effects on other aspects of prehistoric life have been topics of interest among anthropologists and plant geographers since the late 1800s. Numerous works that address substantively the "origins of agriculture" for various times and places have been published over the years (e.g., see Cowan and Watson [1992], Gebauer and Price [1992b], Harlan [1992], Harris and Hillman [1989], and Smith [1992e] for some relatively recent attempts), and still no effort has been judged completely successful in explaining why foragers became farmers. What has become clear, however, is that no single explanation can accommodate, in a "one size fits all" manner, the various developmental pathways exhibited by different farming systems throughout the world (cf. Harlan 1992). Farming systems appear in different configurations at different times in different places for apparently different reasons.

Consider, for example, maize-based subsistence systems of eastern North America. Available stable carbon isotopic[3] and archaeobotanical data indicate that, although maize, beans and gourd/squash formed the subsistence base throughout much of the region, there was considerable variation among different areas in terms of when, how, and to what degree maize was incorporated into local subsistence systems and in terms of what other particular resources were also exploited (Buikstra 1992; Fritz 1990; Scarry 1993; Smith 1989). Minimally, any explanation of the record of maize farming in eastern North America must address

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[2] Throughout this work, I use a definition for farming/agricultural systems derived from that offered by Rindos (1984): agriculture is a set of environment-modifying behaviors employed by people to increase the productivity of particular plant resources.

[3] As detailed in Chapter Four, the stable carbon isotopic composition of archaeological human skeletal remains in the Eastern Woodlands reflects the relative degree to which people's diets were focused on maize.

that and one other particularly noteworthy observation: even though maize was clearly present in many areas of eastern North America since at least A.D. 200, it apparently did not play a major dietary role until some 600 years or more later (Ambrose 1987; Bender et al. 1981; van der Merwe and Vogel 1978).

Although several variables (e.g., climate, demography, resource availability and technology, and social context) have been proposed to be relevant to such an account, how and why maize farming appeared when and where it did in eastern North America has yet to be thoroughly explained. In part, this failure is due to a lack of theoretical sophistication on the part of archaeologists and, in part, it is due to a lack of relevant empirical data. The theoretical tools for developing a successful explanation of maize farming in the Eastern Woodlands are now largely available in the form of models derived from evolutionary theory (Gremillion 1996a; Hart 1999a; Rindos 1984; Winterhalder and Goland 1997). What is needed are more data, but new data generated within the traditional theoretical framework will not suffice; evolutionary explanations have particular data requirements that are not met with traditionally-generated data (cf. Greenlee 2001b).

To meet the empirical requirements, I generated isotopic data for maize consumption from over 250 individuals from relevant skeletal populations of the middle and upper Ohio River valley; these samples were selected to augment the existing isotopic record so that the timing, tempo and trajectory of maize farming in this area could be established. By concentrating my efforts on populations of the middle and upper Ohio Valley, I take advantage of several important features: (1) the generally excellent level of preservation of skeletal materials, (2) the availability of previously-excavated skeletal populations for dietary analyses, and (3) the wealth of previously-published information on subsistence and diet in the region. Dietary data can be arrayed against more traditional parameters to evaluate hypotheses about the appearance, distribution and form of maize-based subsistence systems.

Chapter Two reviews evidence for subsistence and dietary variation in eastern North America during the Woodland and Late Prehistoric periods. Particular attention is paid to the Late Woodland and Late Prehistoric subsistence records of the middle and upper Ohio River valleys. The four main classes of hypotheses (climate, demography, resource availability and technology, and social context) that have been proposed to account for the variable appearance of maize farming in the region are summarized and problems with those scenarios are considered briefly.

Chapter Three outlines the theoretical requirements necessary to address the appearance and spread of maize farming, and concludes that scientific evolution is an appropriate framework for such a study. The tenets of evolutionary theory and their implications for studying subsistence change are briefly reviewed, followed by a reconsideration, in evolutionary terms, of the four hypotheses described in Chapter Two. This step identifies what parameters need to be measured, thereby providing the structure for the remainder of the research. Human dietary data are the most critical need.

Chapter Four presents an overview of the relevant literature on bone chemistry and stable carbon isotope metabolism. In addition to the literature review, results are reported from a controlled-feeding study using pigs. That study demonstrates a clear relationship between isotopic diet and bone chemistry in an animal physiologically similar to humans. Next, potential sources of variation in the isotopic composition of skeletal remains, including sample preservation and preparation, metabolism, environmental situation and animal behavior, are evaluated. Where possible, the integrity of the isotopic signature in previously-analyzed archaeological skeletal populations from the middle and upper Ohio Valleys is considered.

Chapter Five considers variation in isotopic diet associated with maize-based subsistence systems among prehistoric human populations of the Ohio

Valley. The chapter begins with an evaluation of bone preservation for the 251 individuals analyzed as part of this research and presents stable carbon isotope values obtained from those samples. When combined with previously-collected stable carbon isotope ratios from the region, the data set is uniquely dense. Emphasizing how, when and where isotopic diet varied, this chapter seeks to establish the timing, tempo and structure of dietary change in the region, thereby setting the stage for evaluating the four hypotheses identified previously.

Chapter Six begins by describing the environmental setting of the study region and considers variation in subsistence systems that reflects local environmental circumstances. Next, a new model of climatic change covering the past 2000 years for the region, derived from data on pollen, tree rings, lake levels, boreholes, and macrophysical climatic models, is presented. Finally, implications of the first hypothesis, climatic change, are tested by examining the subsistence record in light of relevant data on climatic change.

Chapters Seven through Nine evaluate dietary and subsistence data with respect to the remaining hypotheses identified in Chapter Three. Chapter Seven evaluates the second set of hypotheses, demographic change, by arraying evidence for dietary and subsistence change against available data on population size and structure. Evidence regarding the impacts of resource depletion, competition, and cooperation on subsistence is considered. Chapter Eight considers the third set of hypotheses, resource availability and technology, by evaluating the records for dietary and subsistence variation with respect to changes in the resources exploited and the technologies used to exploit them. Finally, Chapter Nine tests, to the degree possible, the fourth set of hypotheses by examining the dietary and subsistence evidence with respect to variables commonly associated with social context.

Chapter Ten summarizes and integrates the results of the preceding analyses. This research demonstrates how the diverse trajectories of maize-based

farming systems in the Ohio Valley may have been impacted differentially by different causes. Some aspects of the research problem remain unresolved because required data are unavailable.

CHAPTER TWO: MAIZE-BASED FARMING SYSTEMS OF THE EASTERN WOODLANDS

From historical descriptions like those summarized by Swanton (1946) and others (e.g., Hudson 1976; de la Vega 1951), it is clear that maize, beans and squash were important food resources for many Amerindian populations living in eastern North America at Contact. Since so many groups in the East grew those three crops, their cultivation was initially treated by archaeologists as a uniform economic adaptation, as *the* maize-beans-squash triad. Furthermore, it was widely accepted that both the idea of farming and the plants came from Mesoamerica, brought or diffused with other Woodland traits like moundbuilding and pottery (Willey 1966). Thus, the appearance of maize-based farming systems in eastern North America was explained by reference to diffusion of ideas (or actual migration of people) from the primary center of New World agriculture, Mesoamerica (Smith 1992c).

It was also assumed that maize farming had a long history in eastern North America, having been around at least since the Woodland period. Certainly, cultural elaborations of the magnitude documented for the Early and Middle Woodland periods (e.g., mounds, earthworks, and fancy grave goods) *must* have required a dense and well-coordinated population supported by a stable agricultural economy involving maize (Dragoo 1976b; Fowler 1971; Griffin 1967; Morgan 1952; Prufer 1964; Sears 1931; Setzler 1940; Spaulding 1955; Webb 1957; Willey 1966). That belief, together with reported findings of maize from a few mortuary contexts of that age, led most scholars to conclude that maize provided the basis for Woodland subsistence. Although some archaeologists (e.g., Caldwell 1958, 1971; Cleland 1966; Dunnell 1967, 1972) did voice opposition to that opinion, they were clearly in the minority.

WAS FARMING A MESOAMERICAN DERIVATION?

As early as the 1920s and '30s, abundant, well-preserved remains of plants now known to be domesticates, as well as some probably cultivated and several wild ones (various nuts, fruits, and roots), were recovered from Woodland occupations in rockshelters of Ohio, Kentucky and elsewhere (Cowan et al. 1981; Gilmore 1931; Gremillion 1997; Jones 1936). The quantity and/or large size of sunflower (*Helianthus annuus* var. *macrocarpus*), sumpweed (*Iva annua* var. *macrocarpa*), giant ragweed (*Ambrosia trifida*), and goosefoot (*Chenopodium berlandieri* ssp. *jonesianum*) seeds from what he believed was a pre-maize occupation at Newt Kash Shelter (Figure 1) led Volney Jones (1936) to hypothesize an old and separate origin for nontropical plant domestication in the Eastern Woodlands (see also Gilmore 1931; Linton 1924). In hindsight, it is valuable to note that Jones and colleagues decoupled the idea of cultivation from the plants themselves. At the time, it was not readily accepted that the native domesticates really were from contexts predating the introduction of maize and squash in eastern North America (Quimby 1946). Thus, the idea of domestication and plant cultivation may still have been of Mesoamerican origin (e.g., Chomko and Crawford 1978; Dunnell 1965; Ford 1985; Watson and Yarnell 1969), but at least some of the plants involved were local plants.

Support for Jones' hypothesis was eventually provided by the combined results of accelerator mass spectrometry (AMS) dates on individual maize (*Zea mays*) fragments from Early and Middle Woodland contexts and the results of allozyme analyses on gourd/squash. AMS measurements of the maize fragments themselves (Table 1) eliminated claims for a very early introduction (ca. 1000 BC or earlier) of maize into the Eastern Woodlands (Conard et al. 1984). The oldest directly-dated maize specimens in the Eastern Woodlands are from the Holding and Icehouse Bottom sites in Illinois and Tennessee, respectively, while the earliest maize specimens in the Ohio River valley are from the Edwin Harness mound (Figure 1). Clearly, maize was present during the Middle Woodland period, but

there is no evidence for an earlier introduction. The native crops found in trustworthy Early Woodland contexts clearly predate the introduction of maize into the area.

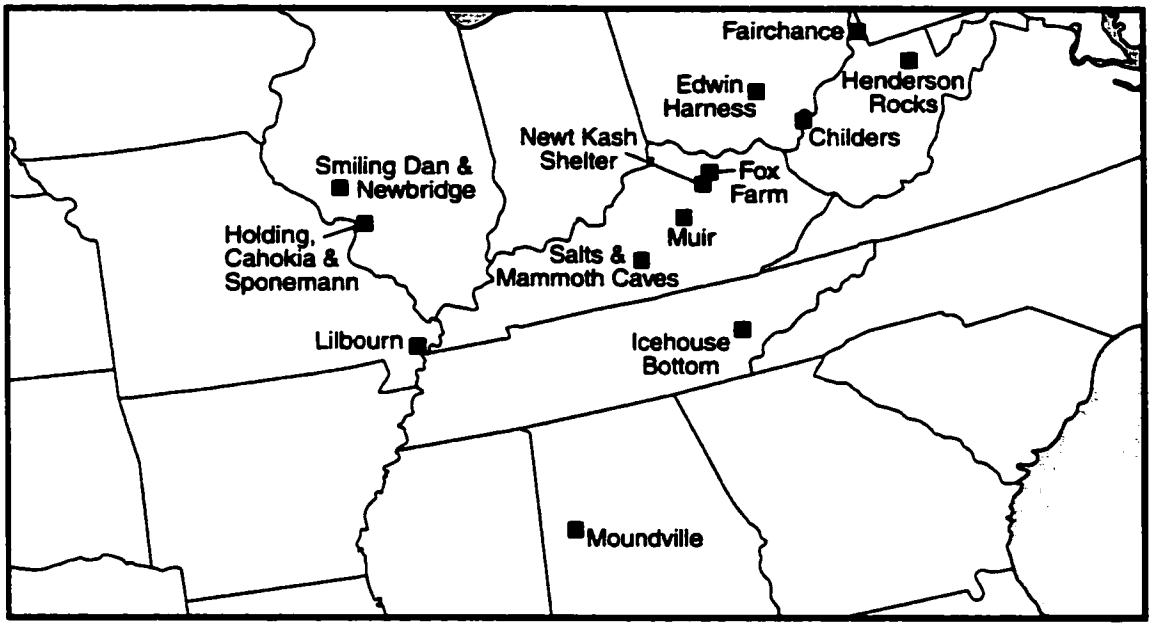


Figure 1. **Archaeological locales of the Eastern Woodlands mentioned in the text of this section and/or plotted in figures.**

This still left open the possibility that the "idea of domestication" and plant cultivation came from Mesoamerica with the squash (*Cucurbita pepo*), roughly 5000 – 7000 years ago (Conard et al. 1984). However, if the early *Cucurbita* specimens were not a cultivated plant (Yarnell and Black 1985) and/or if the gourd/squash taxon cultivated prehistorically could be shown to be a descendent of an indigenous wild taxon (Cowan et al. 1981; Heiser 1985, 1989), that possibility would be eliminated. Indeed, one possible wild ancestor, now known as *Cucurbita pepo* ssp. *ovifera* var. *texana*, had been suggested, but its modern range, limited to central Texas, seemed too restrictive geographically. Allozyme studies on modern squash (Decker-Walters 1993) have identified two lineages, one (*Cucurbita pepo* ssp. *ovifera* var. *ovifera*) from eastern North American and the other (*Cucurbita pepo* ssp. *pepo*) from Mexico. Further, allozyme evidence indicated that not only is the

eastern North American lineage most similar to var. *texana*, but also that var. *texana* likely had a wider geographic distribution in the past than it does now. Another free-growing gourd/squash, *Cucurbita pepo* ssp. *ovifera* var. *ozarkana*, is also a potential ancestor of var. *ovifera* (Smith et al. 1992). The gourd/squash grown prehistorically in the Eastern Woodlands was likely not a Mesoamerican import, but was probably a local product.

Table 1. AMS dates of maize from Middle Woodland contexts in the Eastern Woodlands.

Site (Lab. #)	Reference	Material	AGE (^{14}C yrs BP) **AGE (CAL yrs BC/AD)**[1]
Holding (AA-8718)	Riley et al. 1994	kernel fragment	2017 ± 50 BP **167 BC (37, 31, 20, 11, 0) AD 81**
Holding (AA-8717)	Riley et al. 1994	cob fragment	2077 ± 70 BP **BC 354 (90, 76, 59) AD 72**
Icehouse Bottom (Beta-16576)	Chapman and Crites 1987	kernel fragment	1775 ± 100 BP **AD 26 (244) 529**
Edwin Harness (Beta-18290)	Ford 1987	kernel fragment	1730 ± 85 BP **AD 84 (261, 278, 324, 331, 335) 535**
Edwin Harness (Beta-18291)	Ford 1987	kernel fragment	1720 ± 105 BP **AD 79 (341) 592**

[1] CALIB version 4.1.2 (Stuiver and Reimer 1993) settings: Decadal data set, no lab multiplier, no δ^{13}C correction, Method A, ages formatted as (intercepts) ± 2σ range.

After almost 40 years, the idea that agricultural behaviors were independently established in the Eastern Woodlands prior to the introduction of tropical cultigens has been accepted (Fritz 1990; Smith 1992c; Yarnell 1994). There is no question that maize itself did come ultimately from Mesoamerica. There is no need to assume, however, that agricultural behaviors must have diffused from there as well. Despite its early support among culture historians, diffusion of maize

farming systems from Mesoamerica is an unlikely hypothesis for explaining the appearance of maize-dominated subsistence economies in the Eastern Woodlands.

SUBSISTENCE VARIATION IN THE EASTERN WOODLANDS

Two technologies have significantly impacted archaeologists' understanding of plant exploitation in the Eastern Woodlands. First, use of the flotation technique, which facilitates recovery of small and fragile remains from archaeological sediments (Struever 1968; Watson 1976), has greatly increased the quantity and representativeness of archaeobotanical remains. Second, stable carbon isotope analysis of human skeletal remains has enabled archaeologists to document variation in the consumption of maize (detailed in Chapter Four). Together, these two kinds of data have permitted archaeologists to document geographic and temporal variation in prehistoric plant exploitation.

THE EARLY WOODLAND PERIOD (1000 B.C. – A.D. 1)

Archaeobotanical assemblages from Early Woodland-aged deposits in many areas of the Eastern Woodlands often contain remains of the so-called Eastern Agricultural Complex or EAC (sunflower [*Helianthus annuus*], sumpweed [*Iva annua*], goosefoot [*Chenopodium berlandieri*], maygrass [*Phalaris caroliniana*], erect knotweed [*Polygonum erectum*] and little barley [*Hordeum pusillum*]), along with cucurbits (*Cucurbita pepo* ssp. *ovifera* and *Lagenaria siceraria*) and other weedy, probably cultivated or at least "encouraged," indigenous plants, including amaranth (*Amaranthus* spp.) and giant ragweed (*Ambrosia trifida*) (Fritz 1993; Gremillion 1997; Yarnell 1993). One of the most convincing cases for Early Woodland use of these resources comes from Salts and Mammoth Caves in central Kentucky. There, micro- and macro-remains of several of these cultigens were present in significant amounts in human paleofecal specimens and mummified intestinal contents, as well as in the sediments (Bryant 1974; Gardner 1987;

Gremillion and Sobolik 1996; Marquardt 1974; Schoenwetter 1974; Stewart 1974; Yarnell 1969, 1974a). The implication is that these resources, at some times and places, formed an important part of the diet (Gremillion 1996b; Watson 1974a; Watson and Yarnell 1969; Yarnell 1974b). In most Early Woodland-aged contexts, however, these indigenous crops constitute only a fraction of plant remains; wild plant resources (nuts in particular, along with wild fruits and berries) dominate the archaeobotanical record. Although archaeofaunal assemblages are often not well preserved, the most common faunal remains from Early Woodland occupations are white-tailed deer (*Odocoileus virginianus*) and turkey (*Meleagris gallopavo*), with modest contributions by other mammals (e.g., beaver [*Castor canadensis*], raccoon [*Procyon lotor*], dog [*Canis familiaris*], and elk [*Cervus canadensis*]) and various taxa of fish and turtles (Kelly and Cross 1984).

THE MIDDLE WOODLAND PERIOD (A.D. 1 – 400)

By the Middle Woodland period, seeds of the EAC plants are so prevalent in archaeobotanical assemblages (Figure 2) that it is believed those plants *must* have played a significant role in the subsistence regime (Fritz 1993; Smith 1992b, 1992d; Watson 1989; Wymer 1997). There is, however, substantial geographic variation in the composition of assemblages, particularly with respect to the plants of the EAC. Presumably this reflects variation in local subsistence systems, rather than in preservation, recovery or some other variable (cf. Smith 1992d). This presumption awaits further testing. Although maize was present during this time period (Table 1), it is quite rare in archaeobotanical assemblages and there is no evidence that it played a significant role in the diet then (Bender et al. 1981; van der Merwe and Vogel 1978). Seeds and wood charcoal of second-growth taxa are common in archaeobotanical assemblages from this time period (Chapman et al. 1982; Wymer 1997).

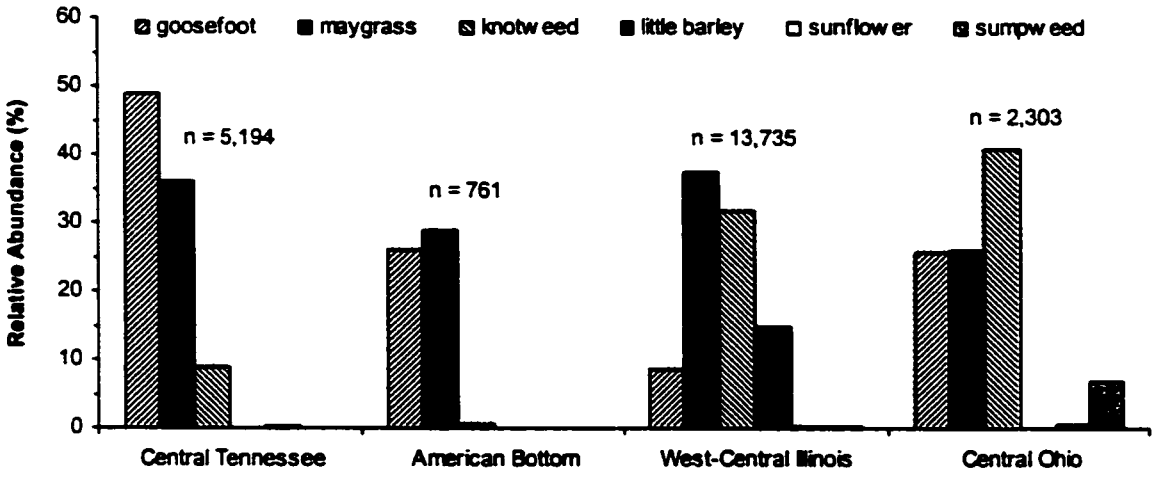


Figure 2. **Relative abundance of seeds from members of the Eastern Agricultural Complex in Middle Woodland assemblages from four regions of eastern North America.** Data from Smith (1992f) and Wymer (1993).

Among terrestrial fauna, those that prefer disturbed habitats (e.g., white-tailed deer and wild turkey) tend to dominate most archaeofaunal assemblages, but fish and turtles are also common (Kelly and Cross 1984; Oetelaar 1990; Tanner 1984). As shown in Figure 3, the relative abundances of different vertebrates (determined using the number of identified specimens [NISP]) vary considerably among archaeofaunal assemblages. Environmental situation and settlement context are important factors (Styles and Purdue 1991).

THE LATE WOODLAND PERIOD (A.D. 400 – 1000)

Subsistence systems of the Late Woodland period are highly variable as well. Figure 4 shows the relative composition of seeds from EAC plants and maize (both cupules and kernels) in assemblages from the early and late portions of the Late Woodland period in two regions of the Eastern Woodlands. Archaeobotanical assemblages from early Late Woodland contexts tend to be similar to those of the Middle Woodland period, with continued, and perhaps increased,

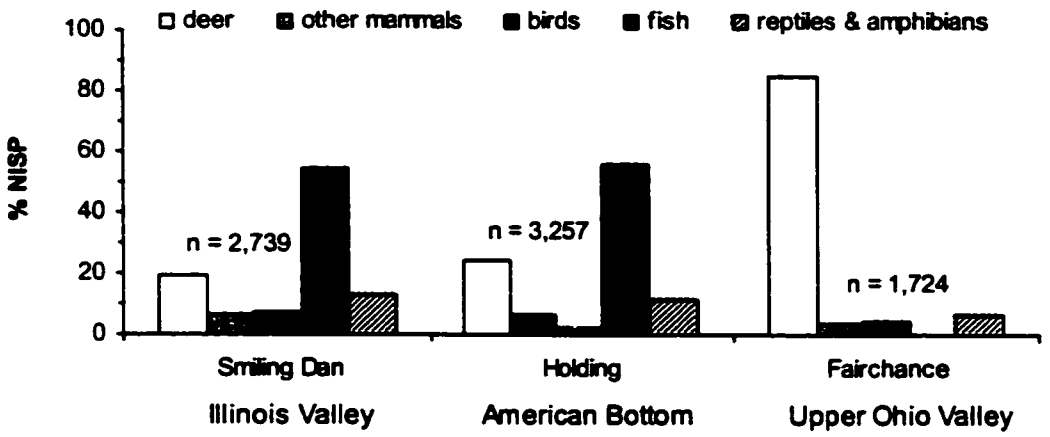


Figure 3. **Relative abundance (% of the number of identified specimens or NISP) of faunal classes in Middle Woodland assemblages from three regions of eastern North America.** Data from Kelly (1989), Styles and Purdue (1991), and Tanner (1984).

reliance on members of the EAC, particularly the starchy ones (maygrass, goosefoot, and knotweed) (Asch and Asch 1981). As in earlier times, these indigenous crops were supplemented by a diverse assortment of wild plant resources, particularly nuts, and occasionally by maize (Watson 1988, 1989; Wymer 1987, 1992, 1993). In later deposits of the Late Woodland period, maize had largely replaced the native crops and wild plant resources in some archaeobotanical assemblages (Wagner 1987, 1989), but not in others (Johannessen 1993a).[4] Assuming again that these data reflect resource exploitation (and not preservation, recovery or some other variable), there is substantial variation in the abundance of these plant remains both geographically and temporally during the Late Woodland.

Animal resource use remained largely unchanged from earlier times. Archaeofaunal assemblages (Figure 5) continue to show great variation with the

[4] This comparison is somewhat complicated because Johannessen (1993a) defined the ending date of the Late Woodland period as the time at which the frequency of maize increases significantly; definitionally, for her, Late Woodland-aged deposits cannot include much maize.

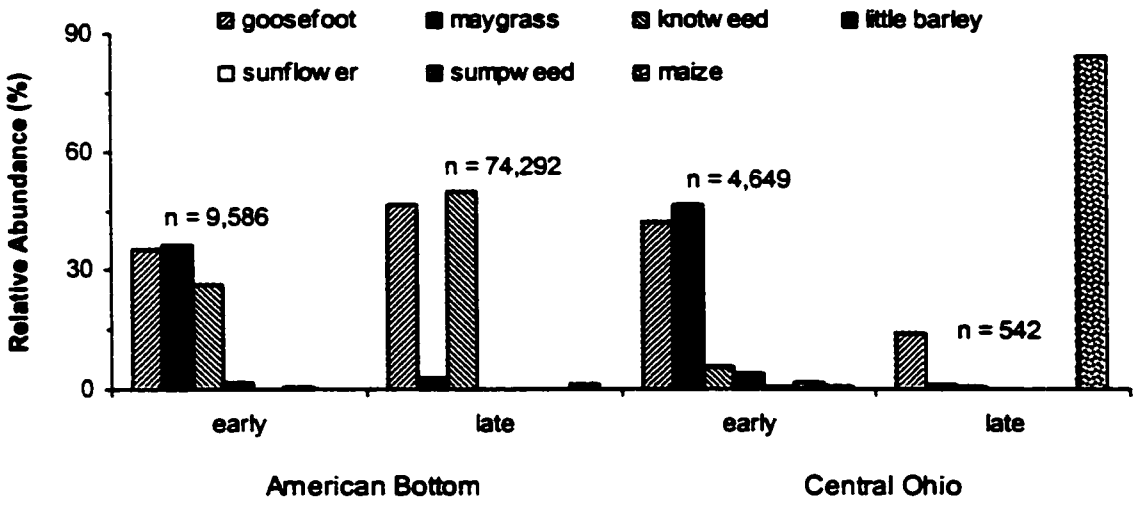


Figure 4. **Relative abundance of seeds from members of the EAC and maize in archaeobotanical assemblages from the early and late Late Woodland periods in two areas of eastern North America.** Data from Johannessen (1993a), Parker (1991), and Wymer (1987, 1990).

local environmental situation (Kelly 1991; Kelly and Cross 1984; Oetelaar 1990; Parmalee 1981; Styles 1981; Theler and Harris 1988). Exploitation of terrestrial fauna emphasized white-tailed deer and wild turkey, but many other taxa (e.g., raccoon, rabbit [*Sylvilagus floridanus*], squirrel [*Sciurus* spp.], waterfowl, fish, turtles, etc.) are represented in assemblages as well.

THE LATE PREHISTORIC PERIOD (A.D. 1000 – 1650)

When compared with those from earlier periods, archaeobotanical assemblages of the Late Prehistoric period have significantly higher frequencies of maize. The contribution of other cultivated resources (e.g., beans, gourd/squash, EAC plants) to these assemblages varies considerably among regions (Figure 6). In some regions, beans are common components of the assemblages (Rossen and Edging 1987), and in others they are not (Lopinot 1994); similarly, in some regions, the indigenous EAC plants continued to contribute significant amounts to subsistence even after maize became a staple crop (Johannessen 1984; Smith 1992d and references therein), and in others they did not (Scarry 1993; Wagner 1987).

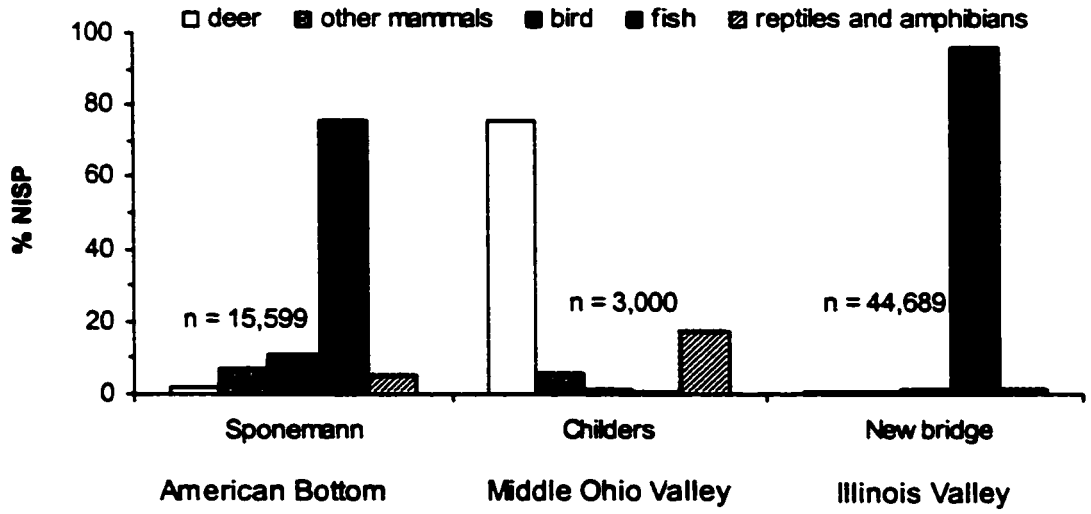


Figure 5. **Relative abundance of faunal classes in Late Woodland assemblages from three regions of eastern North America.** Data from Kelly (1991), Oetelaar (1990) and Styles (1981).

Archaeofaunal assemblages from the Late Prehistoric period are still diverse, but dominated by a few taxa; they continue to reflect an emphasis on acquisition of locally-available resources (Figure 7). Thus, although some subtle changes in the compositions of archaeofaunal assemblages have been identified (Greenlee 2002; Welch 1990), for the most part, animal resource use did not differ substantially from that of the Late Woodland period (Breitburg 1992; Oetelaar 1990). Some exceptions have been noted, however. In the American Bottom, for example, exploitation of waterfowl increased dramatically during the Late Prehistoric period (Kelly and Cross 1984).

THE ISOTOPIC RECORD OF DIETARY VARIATION

Much as archaeobotanical assemblages throughout the Eastern Woodlands vary in their relative composition of plants from the EAC, stable-carbon isotope data collected from the analysis of human skeletal remains demonstrate

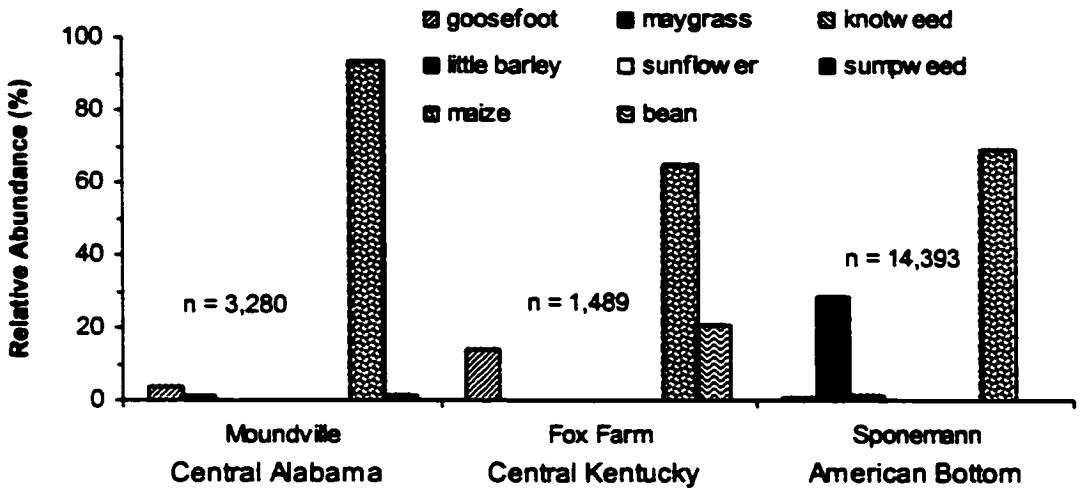


Figure 6. **Relative abundance of seeds from members of the EAC, maize and beans in Late Prehistoric archaeobotanical assemblages from three regions of eastern North America.** Data from Parker (1992), Rossen (1992) and Scarry (1993).

substantial variation in the contribution of maize to subsistence systems of the Eastern Woodlands. Figure 8 compares the isotopic records of southern Ontario, the Western Basin of Lake Erie, the Cumberland River drainage, the central Mississippi Valley and the middle and upper Ohio River valleys. As will be explained in detail later, less negative $\delta^{13}C$ values indicate greater maize consumption than more negative numbers. These plots show how levels of dietary commitment to maize differed among populations of the East and how the incorporation of maize into the diet followed different trajectories.

The $\delta^{13}C$ values for populations of southern Ontario and the Western Basin of Lake Erie exhibit fairly significant isotopic enrichment during the Middle and early Late Woodland periods. In this case, there is little reason to believe that maize consumption is responsible for the higher values. Apparently, lake resources (e.g., fish) there have stable carbon isotope ratios more positive than in the terrestrial environment. Thus, consumption of fish is the likely reason for elevated $\delta^{13}C$ values prior to the introduction of maize and may be a factor in the gradual appearance of the entire trajectory.

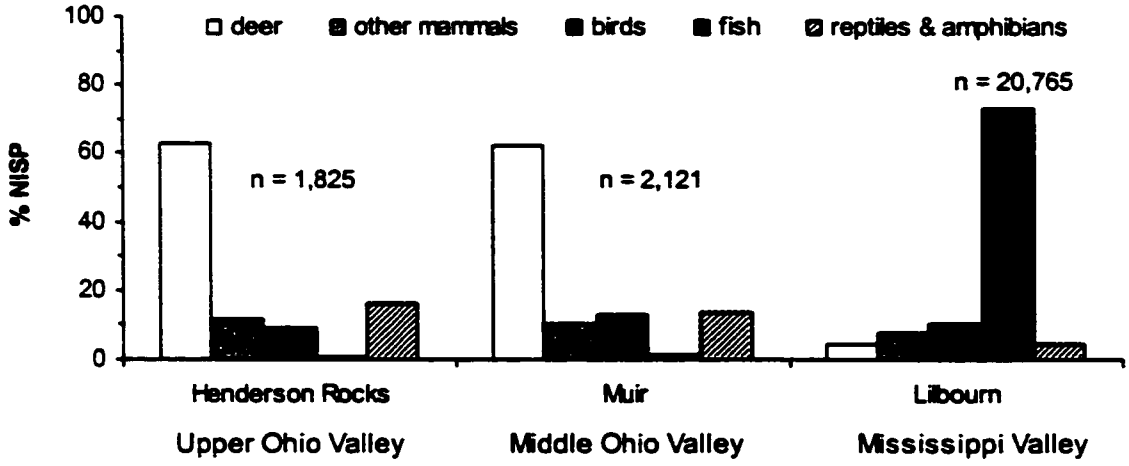


Figure 7. **Relative abundance of faunal classes in Late Prehistoric assemblages from three regions of eastern North America.** Data from Breitburg (1988b), Smith (1975), and Tanner (1976).

In the central Mississippi and Cumberland River valleys, isotopic analyses of Middle Woodland-aged populations are lacking, but Late Woodland-aged populations show no evidence of significant maize consumption. The appearance of individuals consuming significant amounts of maize is rather abrupt and there is little evidence for gradual change in the isotopic diet. The trajectories of the Ohio Valley populations appear to be similar to the more southerly groups, but only one Late Woodland-aged individual has been analyzed isotopically. In each of these two plots, a minor population of non-maize consumers appears to be contemporaneous with the earliest of the maize eaters; this overlap, if not an artifact of poor temporal resolution, suggests that dietary change did not happen synchronously across the populations. Comparisons of these three plots indicate that different processes were probably involved in the change in isotopic diet that accompanied the appearance and spread of maize farming (cf. Buikstra 1992).

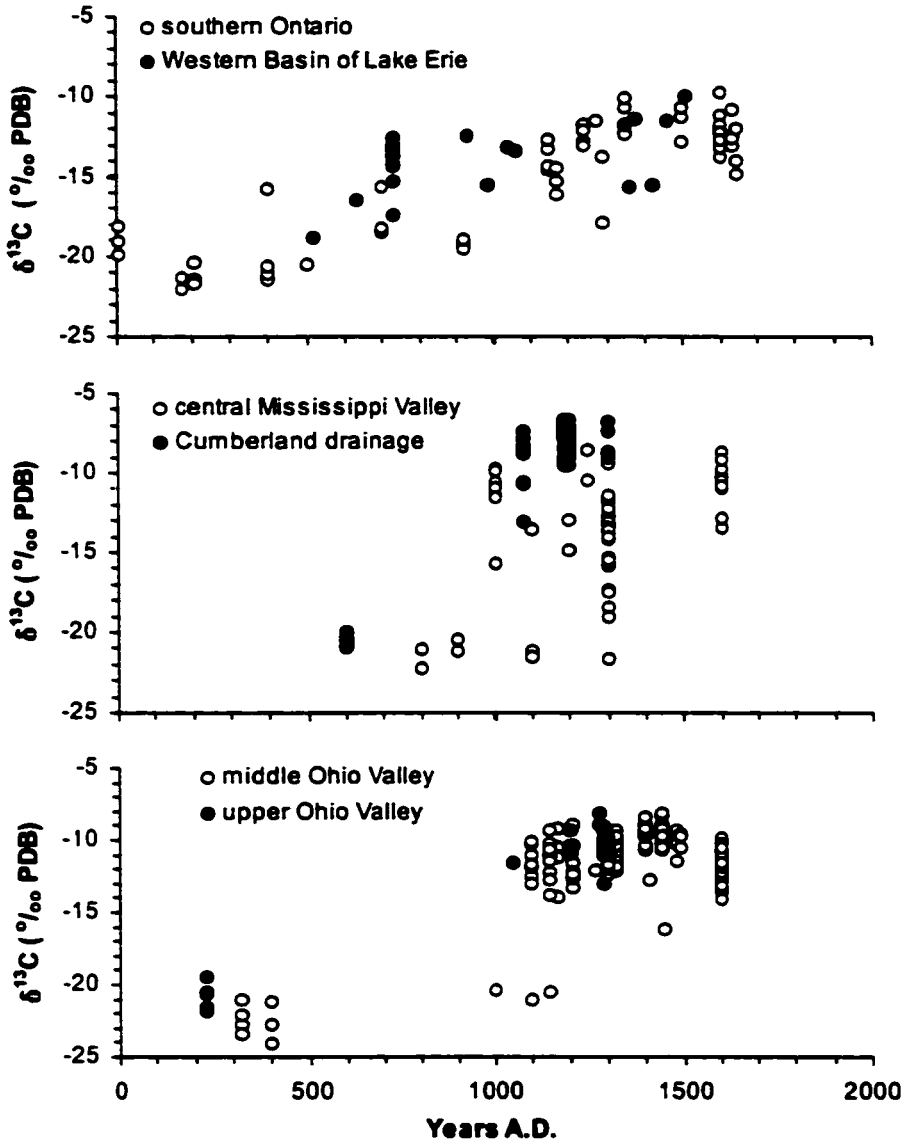


Figure 8. **Stable carbon isotope records for different regions of eastern North America.** Data from Bender et al. (1981), Boutton et al. (1991), Brashler and Reed (1991), Broida (1983), Buikstra et al. (1988), Conard (1988), Farrow (1986), Greenlee (1990, 1998, unpublished data), Greenlee and Dunnell (1990), Hemmings (1977), Katzenberg et al. (1995), Maslowski (p.c.), Schurr (1998), Schurr and Redmond (1991), Schurr and Schoeninger (1995), Schwarcz et al. (1985), Stothers and Bechtel (1987), van der Merwe (p.c.), van der Merwe and Vogel (1978) and Wilson (1997).

IMPLICATIONS

This brief survey of the archaeological subsistence record in the Eastern Woodlands shows that there is substantial temporal and geographic variation in the composition of subsistence systems across the region. Temporally, research into the appearance of maize-based subsistence systems must concentrate on the Late Woodland and Late Prehistoric periods; all evidence suggests that is when the relevant subsistence change occurred. Geographically, one could choose any of several subareas of the Eastern Woodlands as the setting for detailed research into variation associated with the appearance of maize-based subsistence systems. The archaeological record of the Ohio River valley is particularly appealing in this regard because of the apparently rapid commitment to, and high dependence upon, maize documented in the published isotopic and archaeobotanical records.

THE MIDDLE AND UPPER OHIO VALLEY

Although a map of tribal territories based on ethnohistoric accounts might be a logical starting point for defining the boundaries of the study area, such maps typically leave much of the middle and upper Ohio Valley blank (Driver and Massey 1957; Tanner 1987; Trigger 1978). By the time European explorers actually entered the Ohio Valley in the early 1700s, it is believed to have been largely abandoned by native groups due to the combined effects of introduced disease and intertribal warfare. As a consequence of the latter, this no-man's-land was labeled the "Dark and Bloody Ground" (Filson 1797). Although members of the Shawnee, along with other groups, have been documented historically to have occupied and reoccupied parts of the region (Callender 1978; Hunter 1978; Tanner 1987), there is no conclusive evidence to link them with any but the late protohistoric portion of the archaeological record (Brose 1978; Griffin 1937, 1943, 1957; Sharp 1996; Shetrone 1920). Others have noted similarities between archaeological evidence and practices of historic Siouan-speaking groups (Maslowski 1984; Voegelin 1944).

Hence, I refer to the prehistoric archaeological record of the region to define the study area.

The study area (Figure 9), encompassing most of the hydrological territory of the Ohio River, was occupied by populations of the Fort Ancient and Monongahela Late Prehistoric traditions in the Middle and Upper Valley, respectively (Brose 1994; Griffin 1943, 1978; Mayer-Oakes 1955b; McMichael 1968; Tanner 1987). These traditions are identified archaeologically through a variety of artifacts (e.g., pottery, lithics, houses and burials). The culturally-defined

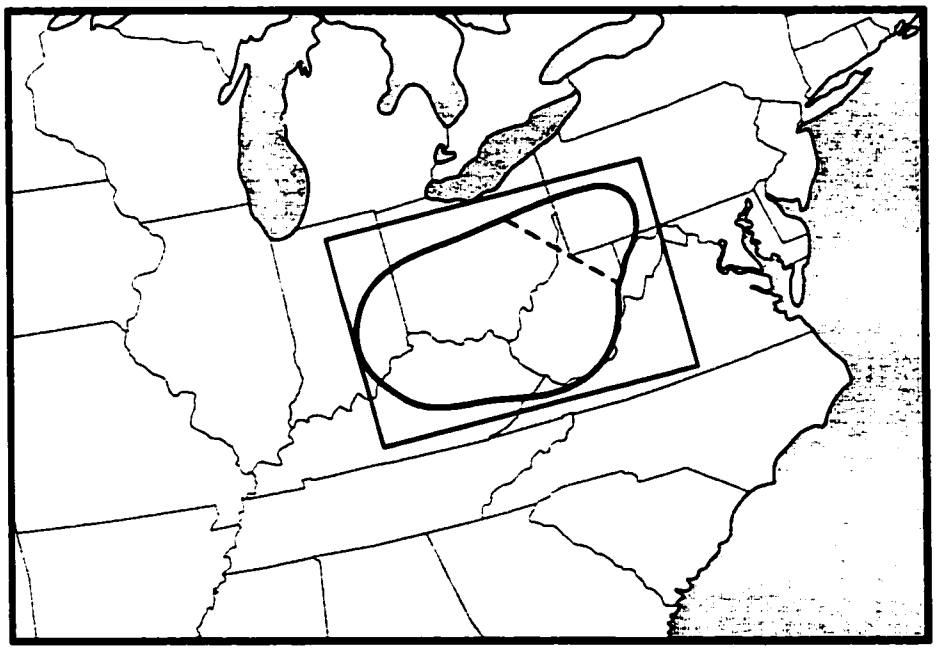


Figure 9. **A portion of Eastern North America, situating the mapped area used elsewhere in this work, with the study region circled in heavy black.** The dashed line indicates the approximate border between the Middle and Upper Valleys.

boundaries of the area are somewhat liberal in the sense that they include, especially to the east and southeast, cultural materials that are sometimes attributed to other historic traditions; yet, the archaeological record of these

outlying areas is similar enough to that of the central portion that they are considered to be closely related.

Along the Ohio River to the southwest, there appears to be an empirical break in the archaeological record of the Late Prehistoric, and perhaps Late Woodland, periods at the Falls of the Ohio near present-day Louisville, KY. Although the area is not well-studied nor are the results well-published, evidence seems to support the notion of a discontinuity between the middle and lower Ohio River valley manifestations, known as Fort Ancient and Mississippian cultural traditions, respectively (Bader et al. 1977; Granger et al. 1981; Griffin 1943, 1978; Kellar 1983; Rafferty 1974). Archaeologists have traced this distinction eastward across central Kentucky (Lewis 1996; Sharp 1996) and this defines the southern border of the study area, as well.

A western boundary, in Indiana, is more difficult to establish. Fort Ancient ceramics have been identified in several eastern Indiana counties (Black 1934; Dragoo 1951; Setzler 1930). Westward into central Indiana, Oliver Phase materials display many attributes in common with Fort Ancient occupations further east; however, they also have similarities with complexes to the north and west (Dorwin 1971). Reflecting this, only southeastern Indiana is included within the study area.

To the north, there are significant differences between the archaeological complexes of central Ohio and those located along the southern margin of Lake Erie (Brose 1994; McKenzie and Blank 1976; Prufer and Shane 1976; Shetrone 1930). Indeed, for much of the time period of interest, there was apparently little contact between these populations – the Till Plains may have provided an effective barrier against the northward spread of Fort Ancient populations. There is evidence for late Late Prehistoric contact along the Ohio and Muskingum Rivers between Whittlesey populations of northeastern Ohio and both Fort Ancient and Monongahela populations (Brose 1978; Graybill 1981).

Empirical boundaries of the study region become fuzzier in the lesser-known mountainous areas to the east and southeast. There is some evidence that these Late Prehistoric populations were expanding through the mountains prior to the disruption resulting from Euroamerican contact (Dunnell 1972; McMichael 1968; Schmitt 1952; Solecki 1949a, 1949b). This is perhaps best illustrated by McMichael's (1968) *Introduction to West Virginia Archeology*, his Map 5 showing a Late Prehistoric expansion of Monongahela into the eastern panhandle of West Virginia (but see Johnson [1999] for an alternative opinion on the source of the Potomac River materials) and an extension of Fort Ancient along the New River into southeastern West Virginia and adjacent Virginia. The New River occupations, along with those from eastern Kentucky, are included in the study area, even though the ceramic assemblages show some historical affinity with Appalachian materials (Applegarth et al. 1978; Dunnell 1983; Graybill 1980a, 1980b; Maslowski and King 1983). These occupations appear to reflect a common economic adaptation with those of the main trench of the Ohio River and its large tributaries; that their environmental situations differ can provide valuable insight into subsistence variation.

SUBSISTENCE AND DIET IN THE OHIO VALLEY

Evidence for subsistence variation in the middle and upper Ohio River valleys is summarized below. The data are from assemblages listed in Appendix A.

THE ARCHAEOBOTANICAL RECORD

Although archaeobotanists recognize that the subsistence systems they seek to study probably varied in unknown ways due to the vagaries of deposition, preservation and recovery, they often assume (recall Figures 2, 4 and 6) that regional and temporal differences in the quantitative composition of their recovered assemblages informs on variation in the composition of the relevant

subsistence systems (e.g., Johannessen 1988; Smith 1992d; Yarnell and Black 1985). When comparing the middle and upper portions of the Ohio Valley, however, this assumption seems to be inappropriate. Of particular interest here is the relatively depauperate nature of archaeobotanical assemblages from the upper Ohio Valley. Whereas archaeobotanical reports on Late Prehistoric-aged assemblages from the Middle Valley often note hundreds, thousands, or more maize kernels (e.g., four to five bushels of maize were recovered from a single pit feature at Madisonville [Figure 10] in 1879 [Hooton and Willoughby 1920] and Dunavan [1992] estimates well over 100,000 kernels were recovered in recent excavations there), Upper Valley

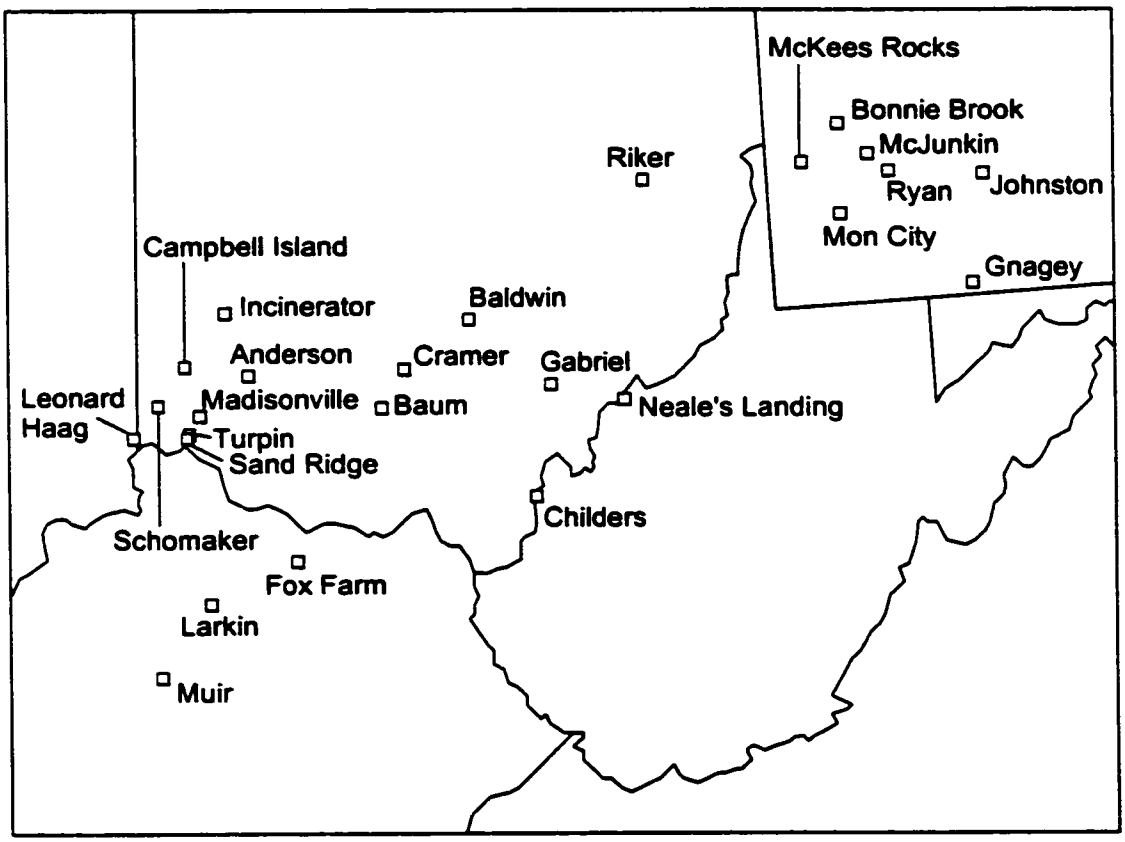


Figure 10. **Ohio Valley locales mentioned in the text and/or indicated in figures of this section.**

reports list maize remains in single or double digits, and rarely into the low hundreds. Isotopically, however, maize consumption appears to have been roughly comparable between Middle and Upper Valley populations (Figure 8).

That more maize has not been recovered from Upper Valley deposits is puzzling. One is led to conclude that the source of the difference between the two areas must lie in preservation or recovery, not in maize exploitation (cf. Johnson 1998). Admittedly, flotation has been an underutilized technology in archaeological research in the Upper Valley. This alone, however, is unlikely to account for the disparate archaeobotanical records. As shown by Wagner (1983) using Late Prehistoric assemblages from the middle Ohio Valley, some classes of archaeobotanical materials, particularly those of large size and high abundance (e.g., maize), are still recovered consistently even when flotation has not been used. She tabulated the contents of 30 assemblages, seven of which were obtained using flotation; of those 30, only three lacked maize remains (and one of those had been recovered using flotation). Thus, if maize were present in the Upper Valley deposits in any significant amount, some should have been recovered, even without flotation recovery techniques. Among the published archaeobotanical data in the upper Ohio Valley, few (n = 4) result from recovery by flotation, and they do not provide much detail (e.g., fragment/seed counts or liters of floated sediment) by which to evaluate recovery success.

Figure 11 compares the composition of several archaeobotanical assemblages from the Middle and Upper Valleys, all of which were recovered through flotation. Because raw counts are not available for all assemblages, the number of seed taxa (identified to the same level, typically to genera or family) within each assemblage are tabulated. These counts should be standardized by the amount of sediment processed because, as the amount of sediment processed increases, the likelihood of recovering rarer taxa increases. Those data are not available, however. Thus, an unknown part of the statistically significant difference

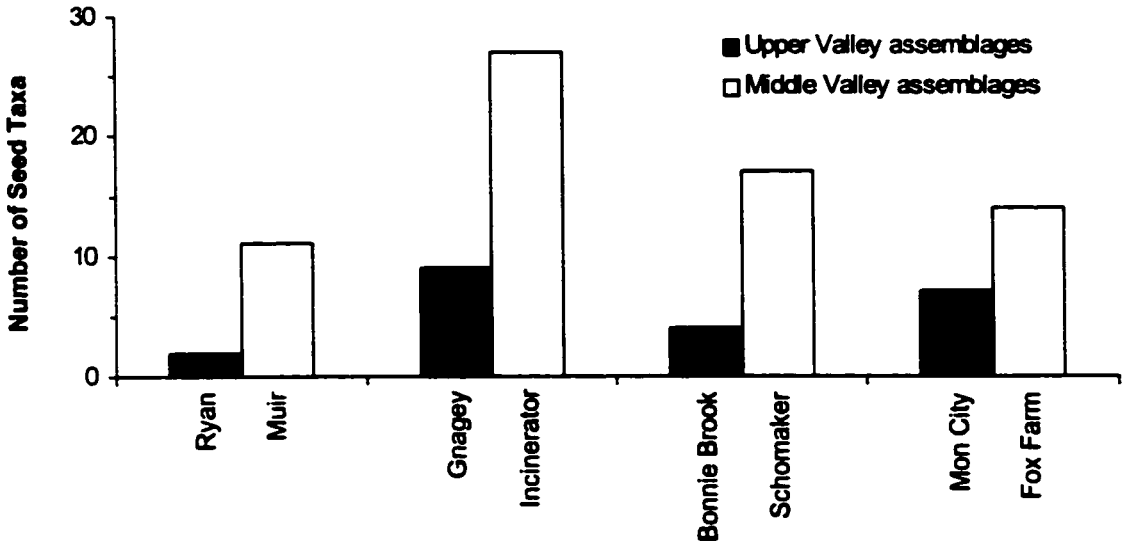


Figure 11. **Number of seed taxa reported for Middle and Upper Valley archaeobotanical assemblages.** Pairs are assemblages of roughly comparable age. Data from Blake (1981), Blake and Cutler (1983), Cowan et al. (1990), George (1974), Hart (1994), Rossen (1988, 1992) and Wagner (1988b).

observed here (t = -3.088; p = .037) is probably due to sampling differences. Some of the difference may also reflect actual variation in the exploitation of these plants (i.e., populations of the Upper Ohio Valley may have simply used a less diverse assortment of plants) and/or variation in food preparation techniques. Given the difference between the two areas in the frequency of maize remains noted above, I suspect that depositional or preservational factors may be at work here as well. Without more information, however, the differences cannot be explained.

Comparability, or rather the lack of comparability, among Ohio Valley assemblages is a serious problem for establishing how subsistence systems may have varied temporally and geographically. Clearly, there are factors other than prehistoric plant exploitation (e.g., deposition, preservation and recovery) that can influence the composition of archaeobotanical assemblages. Although the effects of these factors are not well understood, that they are potential sources of uncontrolled bias that may affect the quantity of remains recovered is readily appreciated (cf.

Yarnell 1982). Variation among archaeobotanical assemblages resulting from deposition and preservation may be compounded when assemblage recovery, identification, and reporting varies, as it apparently does among Ohio Valley assemblages. Given these myriad and uncontrolled sources of bias in the archaeobotanical data set available for this analysis, nominal level data are the most appropriate.

Figure 12 plots the presence of remains from six classes of archaeobotanical remains (nuts, wild fleshy fruits and berries, gourd/squash, EAC plants, maize and beans) during the Late Woodland and Late Prehistoric periods from the Middle and Upper Valleys. Several observations can be made: (1) the total Upper Valley record is quite sparse; (2) maize does not appear in the

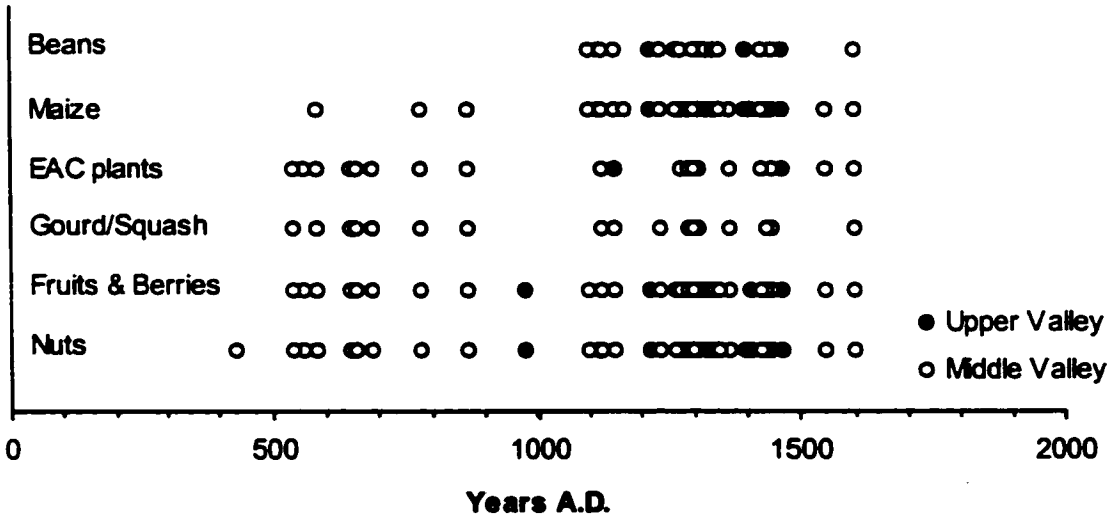


Figure 12. **Presence of botanical remains in Late Woodland and Late Prehistoric assemblages from the Ohio Valley.**

archaeobotanical record of settlements in the Ohio Valley until after A.D. 550; (3) beans do not appear in the archaeobotanical record of the Ohio Valley until nearly A.D. 1100; and (4) although nuts, wild fruits/berries, gourd/squash and EAC plants continue to contribute to archaeobotanical assemblages after subsistence systems became focused on maize, gourd/squash and EAC plants occur less commonly.

Considering only those assemblages recovered with flotation (with higher recovery rates for small items) does not alter these observations.

For more sensitive comparisons without relying on absolute counts, some archaeobotanists have turned to ubiquity, which indicates the relative frequency of samples from each deposit that contain a particular taxon (Hubbard 1980; Johannessen 1984; Pearsall 1989; Popper 1988). Intuitively, it would seem that ubiquity measures might eliminate the impact of uncontrolled biases on subsequent analyses; in a statistical sense, though, using ubiquity does not resolve the problems introduced by these uncontrolled biases because they also affect the mere presence of remains in assemblages (Kadane 1988). However, ubiquity potentially reduces the *severity* of impact that uncontrolled bias might impart to subsequent analyses and it eliminates the false sense of accuracy that raw counts or ratios may provide. Because the archaeobotanical assemblages used here represent a range of depositional and post-depositional contexts and because they were not collected and analyzed with standardized techniques, I rely on ubiquity[5] to illustrate gross patterns in plant exploitation.

Plants of the Eastern Agricultural Complex

In her research with archaeobotanical assemblages from the Middle Ohio Valley, Wymer (1992) found that the starchy seeds of the EAC (goosefoot, maygrass, erect knotweed and little barley) reached their highest levels during the Middle Woodland period, that they remained high through the early part of the Late

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[5] Ubiquity was calculated as ((n samples with taxon present ÷ n samples analyzed) × 100). In using the published data, ubiquity could not be calculated in a standardized manner across all assemblages. The number of samples may refer to the number of features and/or excavated units from which flotation samples were obtained, the number of flotation samples processed, or the number of features in which the relevant material type (e.g., nutshell) was identified. The first variant was used whenever relevant data were available (most cases). The resulting variation is likely small relative to the other comparability problems that plague this sample.

Woodland period, and that they decreased in importance in the late Late Woodland. In addition, she noted that, prior to the Late Woodland period, the starchy seeds appear in relatively even frequencies. However, in the early Late Woodland period, the starchy seed class is dominated by one of two types, either maygrass or goosefoot. By the end of the Late Woodland period and throughout the Late Prehistoric period, goosefoot is the primary EAC plant found in Ohio Valley assemblages (cf. Wagner 1987). The oily members of the EAC (sunflower and sumpweed) are found in much lower frequencies throughout, with sumpweed predominating during the Middle Woodland period and sunflower prevailing thereafter (Wymer 1992).

Figure 13 plots temporal variation in the ubiquity of seeds from members of the EAC; no environmental or geographic patterning is evident. For goosefoot, maygrass and knotweed, the highest ubiquities are obtained during the early part of the Late Woodland period, but their distributions during the Late Prehistoric period vary considerably. Goosefoot is found to have significant ubiquities even near the end of the Late Prehistoric period. In each Late Prehistoric assemblage where seed morphology and/or size have been examined closely, at least some of the seeds were positively identified as the "domesticated" form (*Chenopodium berlandieri* ssp. *jonesianum*), except in one assemblage with a very low ubiquity index (Muir). This suggests that some goosefoot was still being cultivated throughout the Late Prehistoric period, even if many of the specimens represent weedy forms (Gremillion 1993).

Similarly, maygrass has its highest ubiquities during the early Late Woodland, but it is rarely found in Late Prehistoric assemblages. In this sample, it is present in only two Late Prehistoric assemblages (Schomaker and Sand Ridge [ubiquity unknown for the latter]), both located in southwestern Ohio. Because these locales are outside the known range of wild maygrass (Cowan 1978a), the maygrass is believed to have been cultivated. Even though knotweed is not as

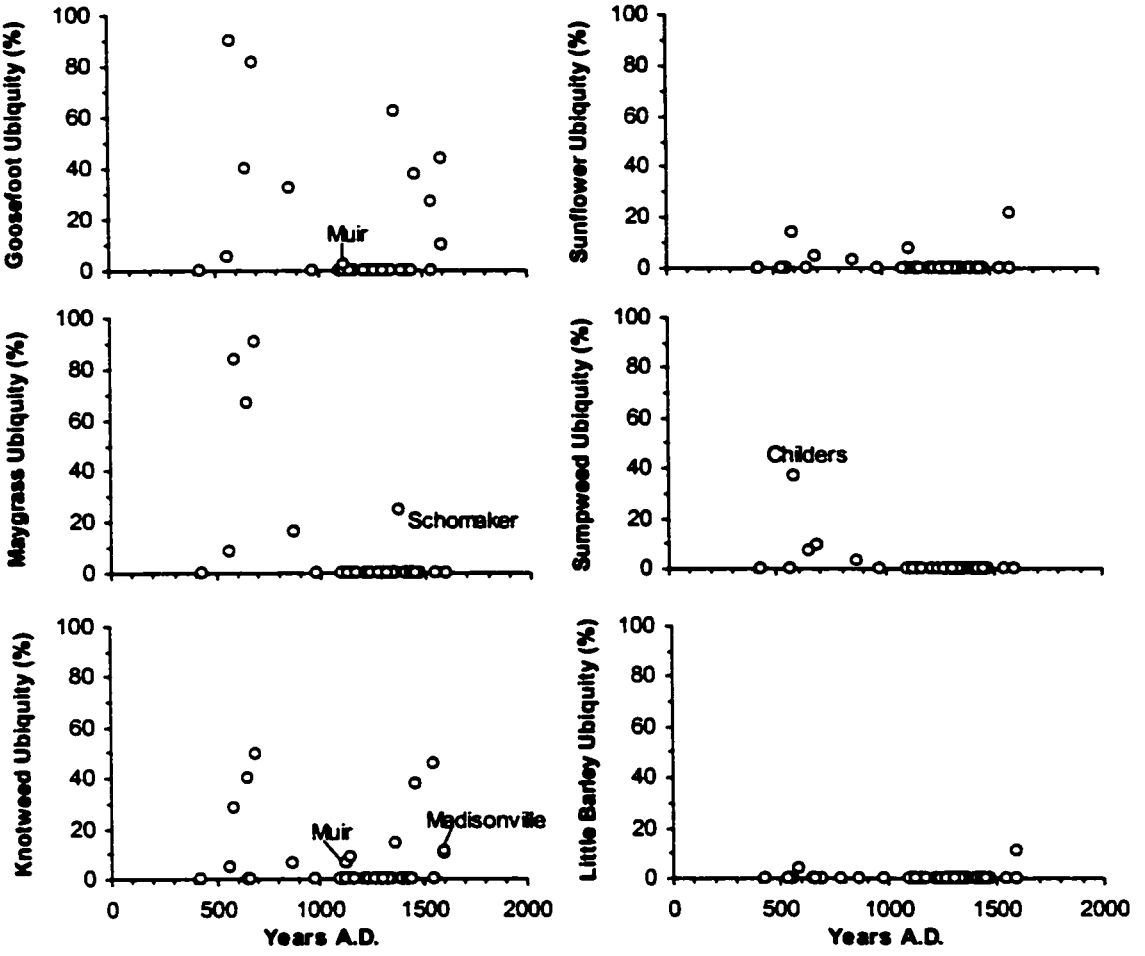


Figure 13. **Ubiquity of seeds from the EAC plants in Ohio Valley Late Woodland and Late Prehistoric assemblages.** Assemblages mentioned in the text are indicated. Data are presented in Appendix B.

ubiquitous as maygrass in Late Woodland assemblages, it remains more ubiquitous in Late Prehistoric ones. For all but two (Muir and Madisonville) of those late assemblages, however, it is listed as *Polygonum* sp. and may actually be a species not known to have been cultivated. As such, these seeds may reflect the accidental inclusion of a "weedy" plant or prehistoric use of a starchy-seeded, wild plant. Only three assemblages include the fourth starchy EAC plant, little barley; it occurs rarely in the two assemblages where ubiquity can be calculated.

Oily seeds (sumpweed and sunflower) remained fairly low in ubiquity throughout the sequence. Sumpweed has a relatively high ubiquity at Childers, where it was found in roughly 40% of the features examined; it was noted for only one Late Prehistoric-aged assemblage, Leonard Haag (ubiquity unknown). In contrast, sunflower occurs in several Ohio Valley assemblages, although generally with low ubiquity. A cache of sunflower achenes has been noted at Cramer, a Late Prehistoric locale, where Goslin counted nearly 10,500 seeds from a single pit (Goslin 1952b). Size data (achene length and width) are available for that and several other locales. As Figure 14 shows, there is no consistent pattern through time in mean sunflower achene sizes in the Ohio Valley.

Potentially more interesting, however, are the size data generated by Goslin (1952b) for a sample of 315 achenes from the Cramer locale. Figure 15 plots those data, which he collected for a size comparison between the archaeological (here corrected for shrinkage during carbonization) and modern seeds. As shown in Figure 15, the Cramer achenes tend to be slightly smaller than the modern, but comparisons with wild *Helianthus* achenes (Yarnell 1978) indicate they are much larger than wild populations. This intermediate size may reflect some degree of reproductive interaction of the prehistorically cultivated plants with wild and/or weedy forms (cf. Gremillion 1993). The small sizes that form the left tails of the length and width distributions are clearly and significantly (length: Kolmogorov-Smirnov $Z = 3.930$, $p < .001$; width: $Z = 5.225$, $p < .001$) underrepresented in the Cramer sample. The absence of achenes in the 7 mm width range is an artifact of rounding in data collection and correction. The Cramer length and width distributions may reflect bias in prehistoric sunflower acquisition or processing, in preservation, in sample recovery, or in sample selection. Unfortunately, it is not clear from Goslin's description where this bias was introduced. The length and width distributions of the modern seeds are also significantly biased (length: $Z = 4.285$, $p < .001$; width: $Z = 3.866$, $p < .001$); this suggests that sample collection

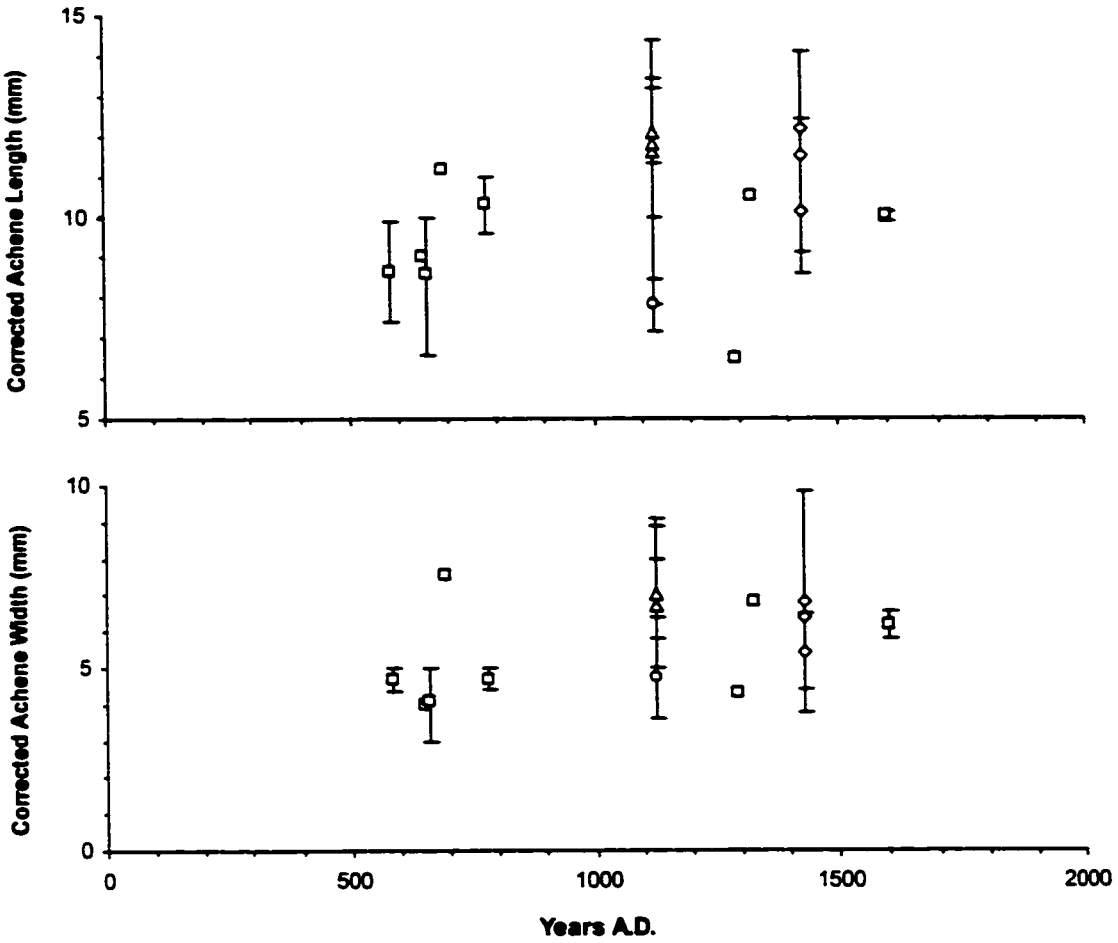


Figure 14. **Mean sunflower achene length and width, with carbonized specimens corrected for shrinkage during carbonization (Yarnell 1978).** Bars reflect range of maximum and minimum values. The circle is an estimated mean (only range data were provided), and the triangles and diamonds reflect three samples from each of two different locales. Data from Dunavan (1993), Rossen (1988), Wagner (1987), Wymer (1990) and Yarnell (1978).

and/or sample selection may be involved. If further research could eliminate the latter three sources of bias (i.e., bias in preservation, recovery or specimen selection), it would suggest that wild or weedy populations were not being exploited and/or that the smallest achenes, even among cultivated populations, were being selected against.

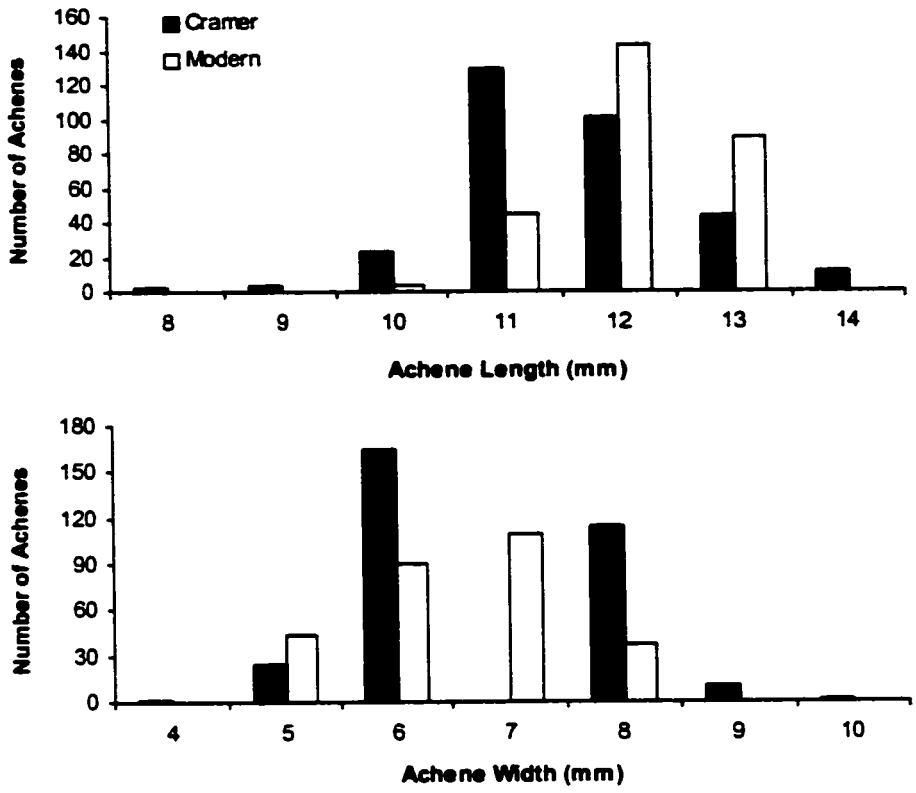


Figure 15. **Sunflower achene lengths and widths from the prehistoric Cramer locale compared with a sample of modern achenes.** Data from Goslin (1952b). Archaeological samples are corrected for shrinkage during carbonization, with length increased by 11% and width increased by 27% (Yarnell 1978).

When EAC resources are considered as a group (Figure 16), their average ubiquity (summed ubiquity ÷ number of EAC taxa with ubiquity data) is nearly as high among late Late Prehistoric assemblages as it is among early Late Woodland ones. It is not clear why the ubiquity of EAC taxa is so low during the late Late Woodland and early/middle Late Prehistoric periods. Sampling problems could be at play. Relatively few assemblages have been analyzed during that time span and thus, the diversity of subsistence systems may not be well-represented. As noted by others (Dunavan 1993; Wagner 1983; Yarnell 1978), many of the Late Prehistoric assemblages from the Ohio Valley were not recovered via flotation and

several of those that were have very small sample sizes. With respect to the latter, however, the number of seeds identified has no relationship with the ubiquity of seeds from EAC taxa (Spearman's ρ = -.116; p = .721). Of course, this pattern may not be a consequence of sampling at all – it may simply reflect temporal variation in resource use as plants were dropped from and/or added to subsistence systems.

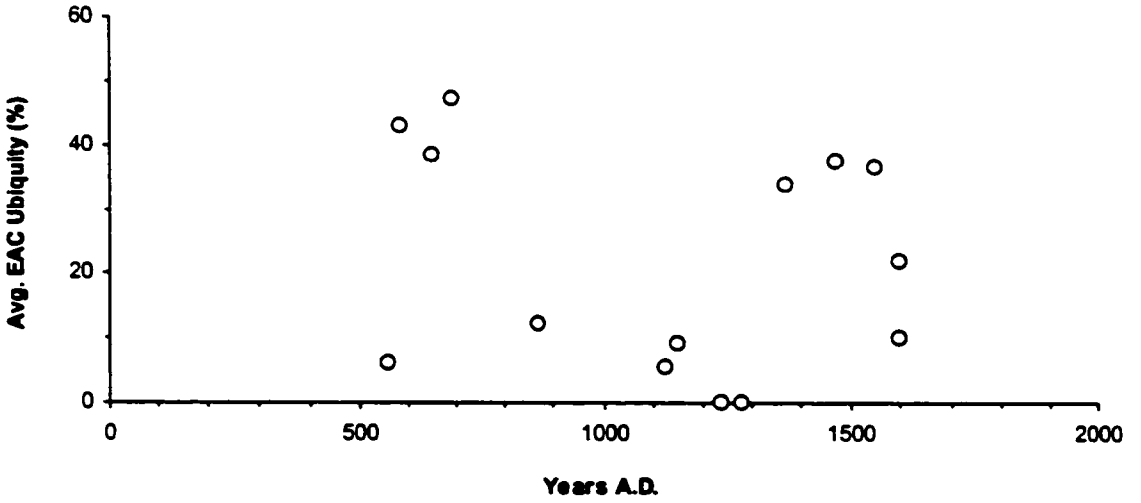


Figure 16. **Average ubiquity of EAC seeds in Ohio Valley assemblages.** Data are presented in Appendix B.

The apparent importance of EAC plants in Ohio Valley assemblages is lower than in some other areas of the Eastern Woodlands, where EAC resources, particularly the starchy seeds, remained substantial contributors to archaeobotanical assemblages until very late in the sequence (Johannessen 1984; Rossen and Edging 1987; Wagner 1987). While these regional differences may reflect differences in excavation and/or botanical recovery strategies, they may also reflect greater dietary dependence upon maize, to the exclusion of native cultigens, by Ohio Valley populations (Rossen and Edging 1987; Wagner 1987).

Squash, Maize and Beans

Despite their widespread use as a resource set at Contact, it is clear that the maize, beans and squash triad was not adopted as a package of agricultural

products. As reviewed earlier, gourd/squash has a long history (ca. 5000 - 7000 years) of use in the East, with maize appearing more recently (ca. 2000 years ago), and beans joining the trio more recently still (ca. 900 years ago). Consistent with this, Figure 12 shows how the presence of gourd/squash, maize and bean remains in Ohio Valley assemblages varied through time. Figure 17 shows temporal variation in the ubiquity of these three crops. In terms of ubiquity, all three plants are highly variable; assuming these data have not been structured by differential preservation, the role of each resource in prehistoric subsistence systems of the Ohio Valley appears to follow a different trajectory.

Gourd/squash remains are not commonly represented in most archaeobotanical assemblages of the Eastern Woodlands; rinds, in particular, are often destroyed during carbonization and degraded by post-depositional processes (Cowan 1997). In her analysis of botanical assemblages from Woodland period locales in the middle Ohio Valley, Wymer (1992) noted that gourd/squash rind fragments are most densely recovered during the early portion of the Late Woodland period. This pattern was also noted by Cowan (1997), who examined gourd/squash seeds, rinds and peduncles from several eastern Kentucky rockshelters spanning nearly 5000 years. He found that, in addition to increased frequencies, gourd/squash remains from early Late Woodland assemblages show morphological changes in the plant toward a thick-walled fleshy squash. Thus, the increase in remains at this time may reflect increased usage of a relatively newly-evolved edible squash (as opposed to earlier uses of squash/gourd as a dietary source of edible seeds and as a hard-shelled container).

Neither rinds nor seeds occur commonly in Late Prehistoric assemblages (Wagner 1987). Rather than an indication of decreased importance in subsistence systems over time, Wagner (1987) suggested that the lower frequency of gourd/squash remains in Late Prehistoric deposits may be due to a change in

gourd/squash processing or disposal techniques that may have decreased the likelihood of seed and rind carbonization.

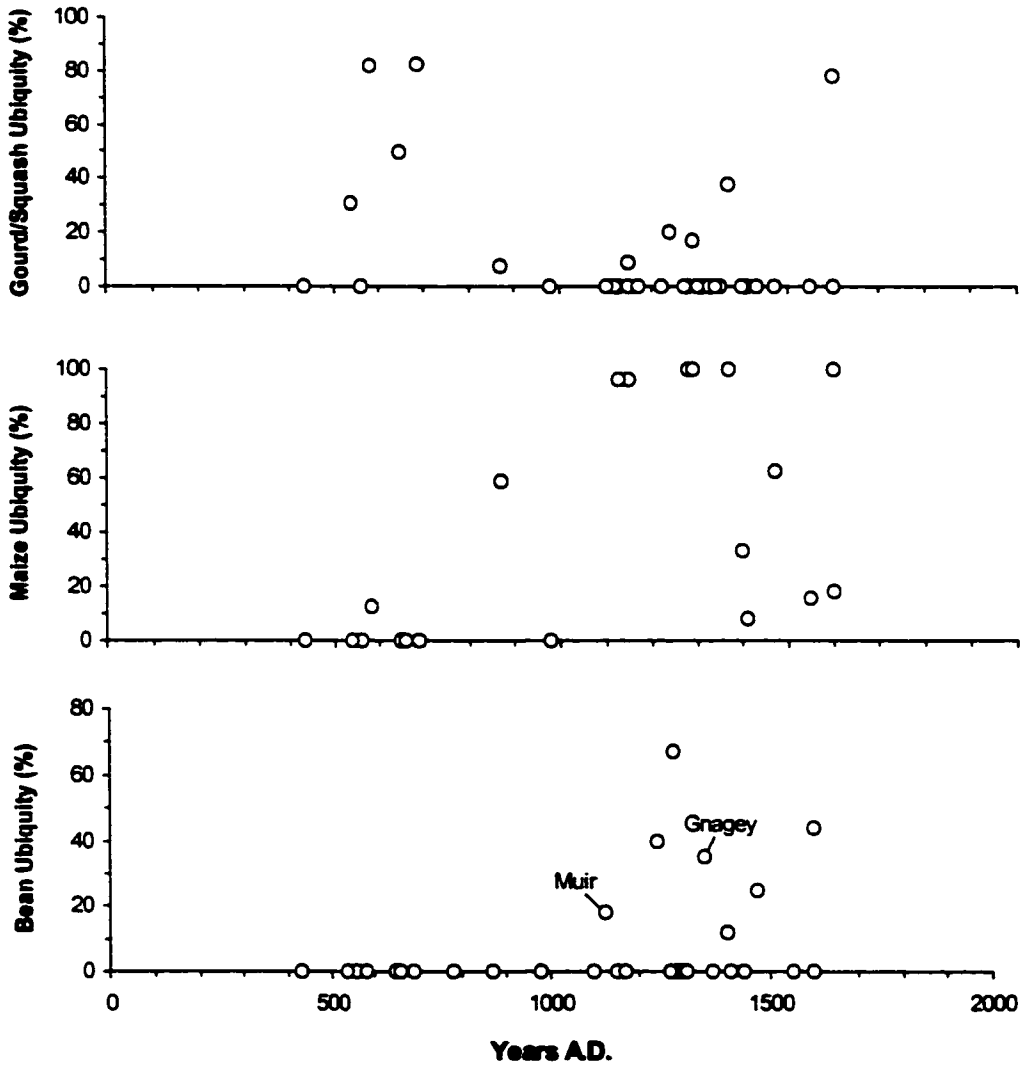


Figure 17. **Ubiquity of gourd/squash, maize and beans in Ohio Valley Late Woodland and Late Prehistoric assemblages.** Assemblages mentioned in the text are indicated here. Data are presented in Appendix B.

Although data are limited, temporal variation in the ubiquity of gourd/squash remains (seeds and/or rind fragments) appears to be bimodal in Figure 17. That is, ubiquities are high during the early part of the Late Woodland,

decreasing through the late Late Woodland and early Late Prehistoric, and increasing again in the middle and into the late Late Prehistoric periods. Why this might be so, if indeed it is so, is not clear; the available data do not allow evaluation of hypotheses regarding preservational conditions, depositional contexts, or morphological characteristics of the plants involved. However, I note that, *if* higher ubiquities of squash remains during the late Late Prehistoric period reflect greater squash use, and *if* such use continued into the historic era, this would be consistent with ethnohistoric observations of substantial cucurbit use throughout the southern portion of the Eastern Woodlands (Swanton 1946). Certainly, this might help resolve the apparent incongruity between the ethnohistoric and archaeological records (Parker 1992), since the bulk of the archaeological evidence comes from early and middle Late Prehistoric assemblages.

In contrast to gourd/squash, maize does not appear in Ohio Valley archaeobotanical assemblages in substantial frequencies until the end of the Late Woodland period (Wymer 1992). Throughout the Late Prehistoric period there, maize continued to be a significant, if not the major, contributor to subsistence systems (Rossen and Edging 1987; Wagner 1987). This is supported by the Ohio Valley stable carbon isotope record (see below). Wagner (1983) suggested that maize use may have increased gradually through time during the Late Prehistoric period, but noted that there is no archaeobotanical evidence to support this notion, nor is it supported by the isotopic record (see below).

Temporal variation in the ubiquity of maize (Figure 17) appears to show a distribution opposite of that for gourd/squash. Initially appearing infrequently in the early Late Woodland period, maize becomes more ubiquitous through the late Late Woodland and into the early and middle Late Prehistoric periods, with an apparent decrease in ubiquity and/or an increase in the diversity of ubiquity values among the several late Late Prehistoric assemblages. I note it is an "apparent" decrease in ubiquity because, of the six late Late Prehistoric

assemblages with maize ubiquity data, three assemblages are from the Upper Valley (which has generally depauperate botanical assemblages) and two of the Middle Valley assemblages are from deposits identified as seasonally-occupied winter camps (and might be expected to have subsistence records that differ from the sedentary villages which comprise the bulk of the sample). Although the trajectory at the end of the sequence may still be unresolved, it is clear that there is a dramatic change in the archaeological visibility of maize between the Late Woodland and the Late Prehistoric periods.

The earliest specimens of maize in eastern North America are not easily characterized in morphological terms because there are so few of them and they are often fragmentary (Fritz 1990, 1992). The morphological characteristics of Late Prehistoric-aged maize are generally better documented. The few data that are available for early maize specimens suggest considerable variation and do not allow clear assignment to any of the maize varieties (e.g., Eastern Eight-Row, Midwestern Twelve-Row, North American Pop) common during the Late Prehistoric period (Fritz 1990; Wagner 1994). Morphological characters (e.g., cob row numbers, cob shape, kernel size and shape) of Late Prehistoric maize in the Ohio Valley show much less variation (Wagner 1986) than in assemblages from other regions of eastern North America (Fritz 1990, 1992; Parker 1991; Scarry 1994). Of those different morphological characters, the number of rows on the cob may be the most useful variable for distinguishing different varieties of the plant (Cutler and Blake 1976). Most Late Prehistoric maize cobs in the Ohio Valley are eight-rowed.

Wagner (1986) argued that the relative homogeneity of maize remains from Late Prehistoric contexts in the Ohio Valley supports the notion of a single introduction of the crop there, rather than several introductions from multiple genetically-isolated sources. This is not to say that the initial introduction of maize into the area during the Early or Middle Woodland occurred only once; as Hart (1999a) made clear, the most probable scenario involves multiple introductions and

extinctions of maize in the East. The maize farmed by Late Prehistoric populations of the Ohio Valley was presumably the product of several hundred years of evolution, in relative isolation, of a small founder population which subsequently spread throughout the region. The isozyme data for Northern Flint maize, a probable historic descendant of Eastern Eight-Row, certainly seems to support this idea (Doebley et al. 1986); Northern Flint is isoenzymatically distinct from maize groups from Mexico and the American Southwest (although it has more in common with the Southwestern types), suggesting it was long isolated from those other populations. Wagner (1986) further noted that there is more variation in maize among assemblages from the southern reaches of the area, where larger proportions of the cobs have higher numbers (10 and 12) of rows. She indicated this may be due to environmental conditions and/or hybridization with higher-rowed populations.

Figure 18 maps the relative frequency of 8-row maize cobs[6] in assemblages from the Middle and Upper Valleys. Data from six assemblages with very small cob counts (Anderson [n = 1], Baum [n = 2], Gabriel [n = 1], Ryan [n = 2], Turpin [n = 2] and Thompson [n = 4]) were removed from consideration in order to eliminate a significant sample size effect on the number of maize types present (final $\rho = .550$; $p = .100$). There is a clear geographic pattern in the frequency of 8-rowed maize cobs in the area; they comprise smaller fractions of the maize cob assemblages in southerly locales, with 10- and 12-rowed cobs increasing in frequency there. The cob assemblage from Baldwin is the apparent exception to this trend; samples from additional locales in that area may provide enlightenment as to why this might be. To the degree that the ages of these 10 cob assemblages are known, a nonparametric Kruskal-Wallis test indicates the relative frequency of 8-row cobs does not vary significantly across time periods ($\chi^2 = 3.800$; $p = .150$).

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[6] In all contour maps, I use a kriging algorithm to generate isolines that express general geographic patterns among the locales; because that algorithm type relies on some interpolation to establish the isolines, where any particular archaeological locale falls within the contours should not be taken literally.

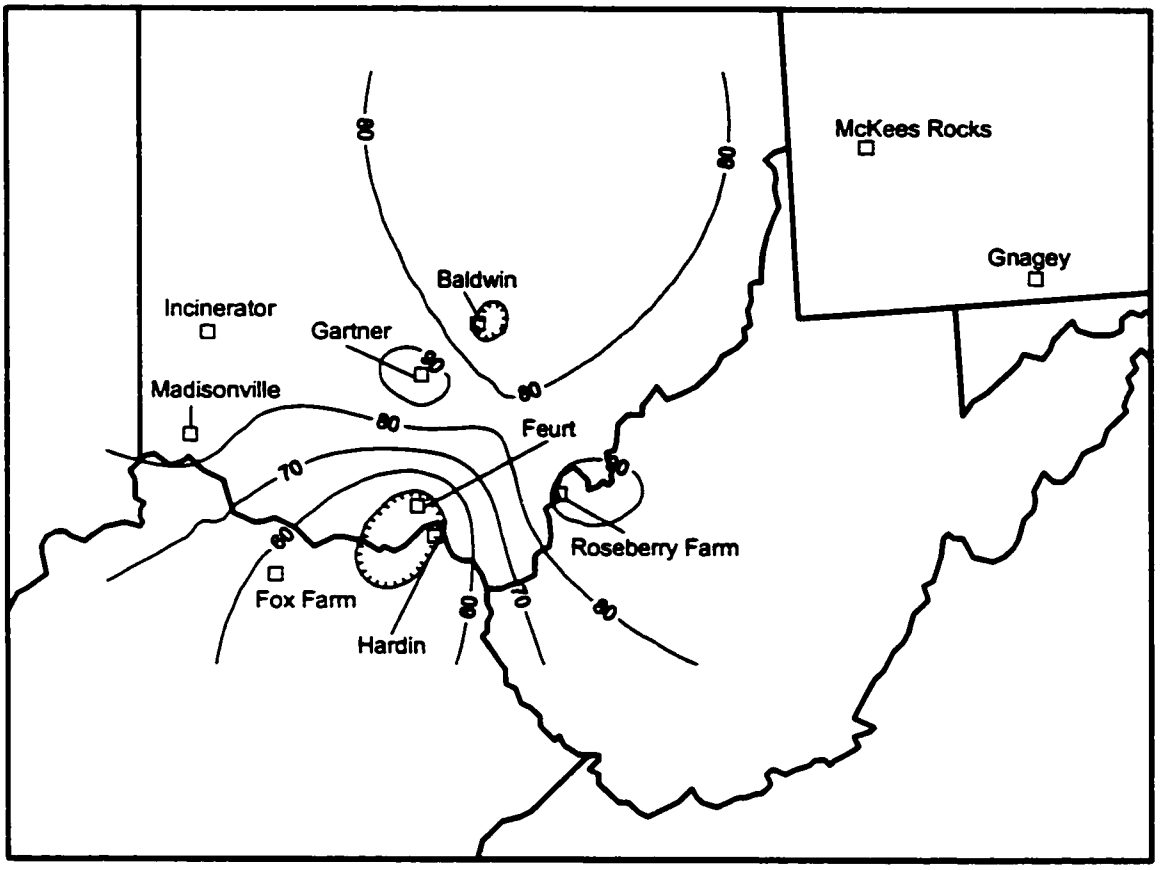


Figure 18. **Geographic distribution of 8-row maize cobs in Late Prehistoric assemblages (isolines show relative abundance).** Data from Blake and Cutler (1983), Jones (1968), Rossen (1992) and Wagner (1987).

Common beans were a late addition to the subsistence systems of the Ohio Valley (Figure 17). If recent AMS determinations on beans from assemblages in the Northeast are any indication, this addition was perhaps later than currently believed (Hart and Scarry 1999). Hart and Scarry's analysis included beans from one Upper Valley locale considered here (Gnagey); the beans were found to be more recent (ca. A.D. 1350) than the generally understood age(s) of the occupation(s) with which they were associated (ca. A.D. 1125). Similarly, several early Late Prehistoric bean specimens from Middle Valley assemblages have been found to date to the late 1200s and later (Hart et al. 2001). Unfortunately, beans from the early Late Prehistoric Muir assemblage (ca. A.D. 1125) have not been dated directly;

this assemblage currently provides the best evidence for early bean in the region (Rossen 1988). Although still earlier than beans are found elsewhere in the Eastern Woodlands (Fritz 1990; Hart and Scarry 1999), this relatively late date in the prehistoric sequence would seem to suggest that beans required an established agroecology for successful cultivation.

Beans are common constituents of Late Prehistoric archaeobotanical assemblages in the Ohio Valley, more so than other areas of the Eastern Woodlands (Riley et al. 1990). Although they are not typically found in great density or ubiquity, relatively large bean assemblages (with unknown ubiquity) have been obtained from some late Late Prehistoric occupations such as Campbell Island, Fox Farm and Larkin (Rossen 1992; Wagner 1986). The generally low density of beans in archaeobotanical assemblages has been suggested to reflect a low likelihood of preservation through carbonization (associated with how they were processed) rather than simply infrequent usage (Fritz 1990; Smith 1992d). By implication, where beans are found in large numbers must reflect some difference in processing or deposition, but this has not been shown to be the case.

Modern varieties of beans vary with respect to their length:width ratios (Wagner 1986), and this measure may be useful in documenting the prehistoric use of different bean varieties. Although the effects of carbonization on bean dimensions are not well documented, experiments have shown that bean shrinkage and/or expansion occurs proportionately so that the ratio of bean length to width is not significantly altered (Bennington 1980, cited in Wagner 1986). Analyses of bean shape (length:width) have documented relatively little variation within and between assemblages throughout the Ohio Valley. Where measurements on individual specimens from a locale have been reported, the distributions of bean length:width measurements do not differ from a normal distribution. Similarly, when all measured beans are considered together, a unimodal curve results that does not depart from a normal distribution.

As Figure 19 shows, there appears to be some geographic patterning to the mean bean length:width ratio, with the relatively longer beans concentrated in southwestern Ohio and a pocket of shorter beans centered over the Hocking and Muskingum Rivers. Assuming bean shape is not influenced by environmental conditions, perhaps this distribution of bean shapes reflects patterns of cultural interaction in the form of bean seed exchange. More data, of course, are necessary to test such a scenario. There is no apparent change in bean length:width dimension across time periods ($\chi^2 = .076$; $p = .963$).

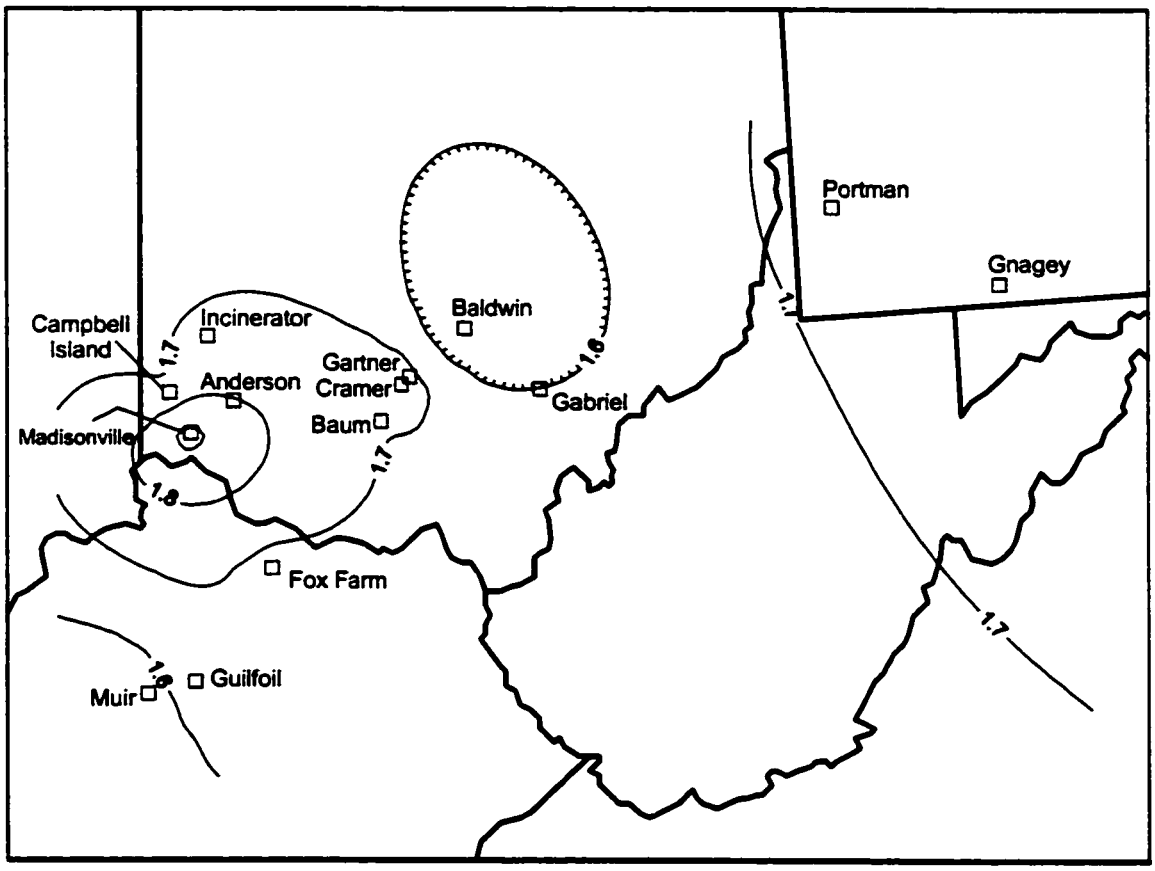


Figure 19. **Average bean length:width ratios in Late Prehistoric assemblages.** Data from Blake and Cutler (1983), Buker (1993), Rossen (1987, 1988, 1992) and Wagner (1987).

Nutmeats and Nutshells

Among Woodland period assemblages, the frequency of nutmeats and shells increases into the early Late Woodland and decreases thereafter (Wymer 1992). Although nut remains are found in Ohio Valley Late Prehistoric assemblages, they do not approach the levels found in assemblages from earlier times and they may actually decrease through time during the Late Prehistoric period (Rossen 1992). The compositions of the nutshell collections also may vary somewhat across different environments and perhaps with time, but hickory and walnut (more so black walnut than butternut) generally predominate, with acorn and hazelnut being less frequent contributors (Lopinot 1988; Wagner 1987; Wymer 1992).

Nut (both shell and meat) ubiquity data for Ohio Valley archaeobotanical assemblages are shown in Figure 20. The values are average ubiquities (summed ubiquity/number of nut taxa with ubiquity data). Interestingly, some amount of nutshell was identified in every assemblage considered here. The distribution appears to be bimodal, with one peak in mean ubiquity during the Late Woodland and another during the middle and late Late Prehistoric periods, but this may be due to the lack of quantified data from early Late Prehistoric assemblages. The identification of a second, later peak in mean ubiquity is apparently at odds with data on nutshell density. I note that there is no statistically significant relation (in terms of rank) between the number of identified seed/nut remains and average nut ubiquity ($\rho = .500$; $p = .082$). If this bimodal pattern holds with the addition of new data, information about depositional context may distinguish between two alternative scenarios: that nut exploitation increased during the Late Prehistoric period or that different treatments (e.g., burning nuts and/or shells for fuel) resulted in increased preservation. Increased nut exploitation during the Late Prehistoric period may reflect greater yields that resulted from increased exposure of the trees to sunlight (Gardner 1997) along clearings generated for crop cultivation.

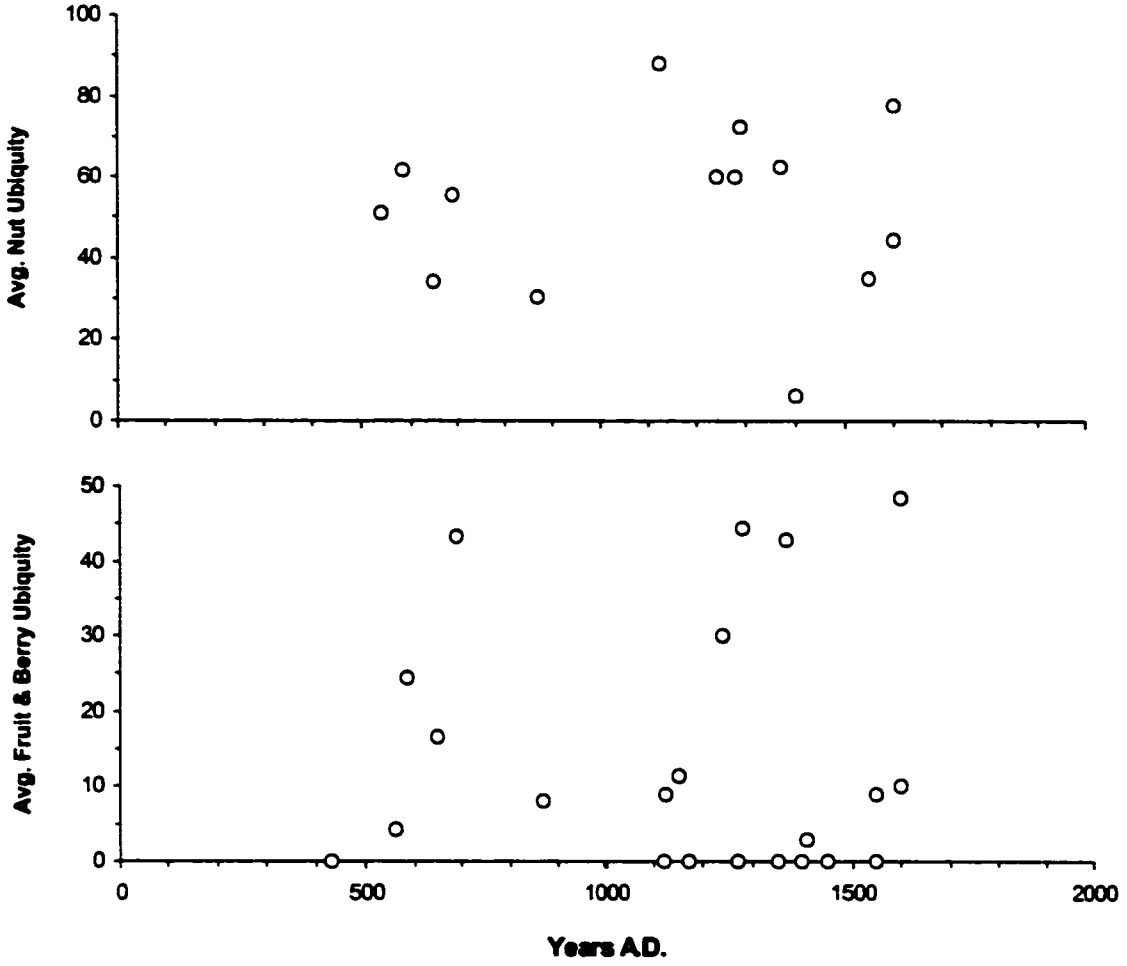


Figure 20. **Ubiquity of nutshell and meat and fleshy fruit and berry seeds in Ohio Valley Late Woodland and Late Prehistoric assemblages.** The values plotted represent average ubiquities for several taxa (nuts = hickory, walnut, acorn, hazelnut and chestnut; fruits and berries = hackberry, persimmon, hawthorn, honey locust, mulberry, sumac, plum, cherry, blackberry, raspberry, black nightshade, elderberry, grape, pawpaw and blueberry). Data are presented in Appendix B.

Fruits and Berries

Seeds from fleshy fruits and berries are also important constituents of Ohio Valley archaeobotanical assemblages throughout the Late Woodland and Late Prehistoric periods. Sumac, grape, and plum/cherry are the most frequent taxa of fruits recovered. Because sumac seeds are so common and abundant in Late

Prehistoric assemblages, it has been suggested that plant was at least protected, if not cultivated (Rossen 1992). Sumac invades cleared areas, though, and its frequency in Late Prehistoric assemblages may simply be a consequence of the greater availability of such habitats due to swidden farming techniques.

The fruit and berry ubiquity data plotted in Figure 20 again suggest a bimodal distribution and, again, there is no relation (in terms of rank) between the number of identified seed and nut remains and fruit/berry ubiquity ($\rho = .126$; $p = .696$). Most of the fruit/berry taxa considered here do well in disturbed environments; that they are common in later deposits may reflect changes in the local ecology associated with farming. Indeed, when the seed and wood charcoal data are combined with the archaeofaunal record, there is significant evidence throughout the Late Woodland and Late Prehistoric periods for the kinds of habitat modification that would be a consequence of burning (Day 1953; Maxwell 1910; Pyne 1982) and/or swidden farming (cf. Conklin 1957; Linares 1976).

THE ARCHAEOFAUNAL RECORD

Reports describing Ohio Valley archaeofaunal assemblages frequently comment on the apparent reliance of prehistoric populations on three taxa: white-tailed deer (*Odocoileus virginianus*), wild turkey (*Meleagris gallopavo*) and box turtle (*Terrapene carolina*). To be sure, many other animals were exploited as well. Other animals in the top-ten list of most frequently found fauna in Ohio Valley assemblages include elk (*Cervus canadensis*), black bear (*Ursus americanus*), squirrel (*Sciurus* spp.), raccoon (*Procyon lotor*), beaver (*Castor canadensis*), woodchuck (*Marmota monax*), and rabbit (*Sylvilagus* spp.); remains from a variety of other mammals, birds, turtles, fish and mussels are also often found. Most analyses of Ohio Valley archaeofaunal assemblages have found that faunal exploitation varied more geographically or environmentally than temporally.

Except in a handful of cases, deer bone makes up the bulk of Ohio Valley faunal assemblages in terms of NISP. Of the fifty assemblages with quantitative information available, deer alone comprises over 70% of the vertebrate component[7] for nearly 70% (n = 34) of them. Because bones from large animals are often more likely to be preserved than those from small animals under inhospitable conditions, it is important to assess the likelihood that preservation conditions have structured the relative abundance of deer (and other) bones in these assemblages. A preservation classification[8] was developed and each assemblage was evaluated accordingly. A Kruskal-Wallis test indicates that the abundance of deer bone does indeed vary with preservation ($\chi^2 = 11.703$; $p = .008$); removal of the most poorly-preserved assemblages (Goolman, Hansen, Childers, Wylie and Portman [Figure 21]) eliminates the significant impact of preservation on deer abundance ($\chi^2 = 1.022$; $p = .600$). Importantly, the abundance of deer bone in the remaining assemblages does not vary significantly with sample size ($\rho = .224$; $p = .140$), and a Kruskal-Wallis test shows no differences among assemblages collected using different recovery techniques ($\chi^2 = .925$; $p = .630$).

The relative abundance of deer bones does not vary with assemblage age ($\rho = -.158$; $p = .300$). However, in a subsample of these assemblages (only Late Woodland and early Late Prehistoric assemblages from the middle Ohio Valley), the variance in deer abundance was found to be significantly less for assemblages accumulated by maize farmers than for those that predate maize farming (Greenlee 2002). In the larger sample of this research, a Levene's test for homogeneity of variance indicates that pattern is maintained ($F = 5.036$; $p = .030$). I (Greenlee

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[7] Fish, reptiles, amphibians, mammals weighing less than 0.5 kg, and birds with total length less than 6" have been removed from consideration in an effort to reduce the impact of different recovery techniques on inter-assemblage comparisons (Appendix B).

[8] Archaeofaunal assemblages are classified with respect to preservation (Appendix B) using four lines of evidence: physical condition of remains, soil pH, soil texture and condition of calcareous temper.

2002) suggested the lower variance among post-maize farming assemblages indicates greater similarity in local ecologies resulting from landscape modifications associated with maize farming. Although temporal variation in the settlement contexts represented by these assemblages (e.g., fewer logistic camp deposits) may be at play, there is no statistical difference in the variance of deer bone abundance between sedentary village and seasonal camp deposits ($F = 1.401$; $p = .242$).

When mapped, the contribution of deer to faunal assemblages is patterned geographically (Figure 21). The greatest emphasis on deer appears to have occurred in the Middle Valley, along the Ohio River. Deer contribute less to assemblages of the Upper Valley, to the western Till Plains and to the eastern Bluegrass areas. This pattern probably reflects, in part, the availability and relative economic value of deer and other taxa, determined by a combination of physiographical and ecological conditions, scheduling and acquisition technology.

Taxa that prefer particular habitats occur more frequently in assemblages from locales adjacent to those habitats. For example, aquatic and semi-aquatic taxa are relatively more prevalent in assemblages from bottomland than from upland locales (Greenlee 1994). As another example, Breitburg (1988b, 1992) observed that the relative contribution (by meat weight[9]) of animals like elk

[9] Meat weights are estimated as the average amount of meat available on an individual of a given taxon multiplied by the minimum number of individuals (MNI) that could be responsible for that taxon's contribution to a faunal assemblage. Thus, even though the NISP of a relatively rare taxon like bear may be only a fraction of the NISP of an abundant taxon like deer, because bear are larger animals, they may have contributed as much or more meat to the subsistence system than deer. From this perspective, smaller animals like turkey and box turtle would contribute little to the overall subsistence package. The use of meat weight as a counting unit has been criticized on several counts (Grayson 1984); criticisms include its reliance on estimates of MNI, which are plagued by aggregation problems, the imprecision associated with estimates of available meat on an animal, and the assumption that meat is the only basis for comparing

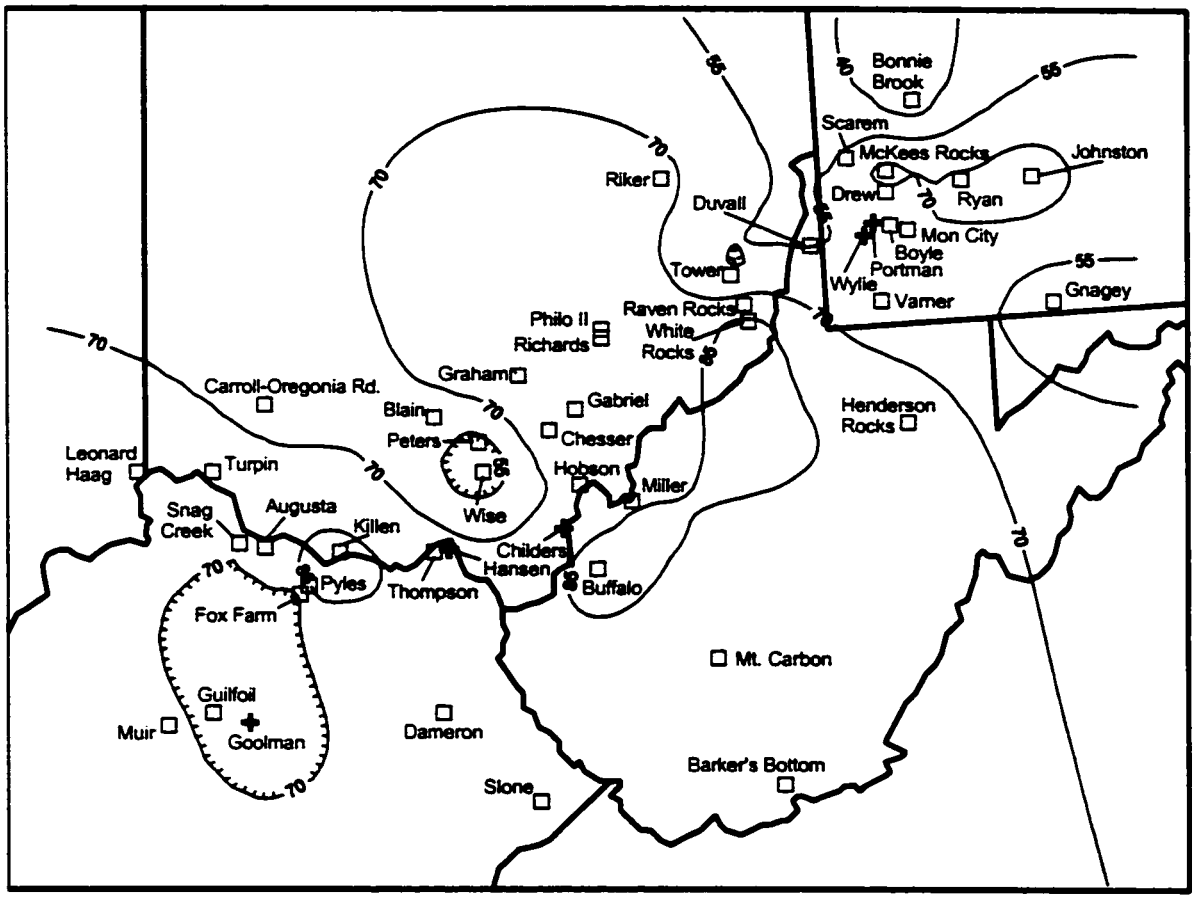
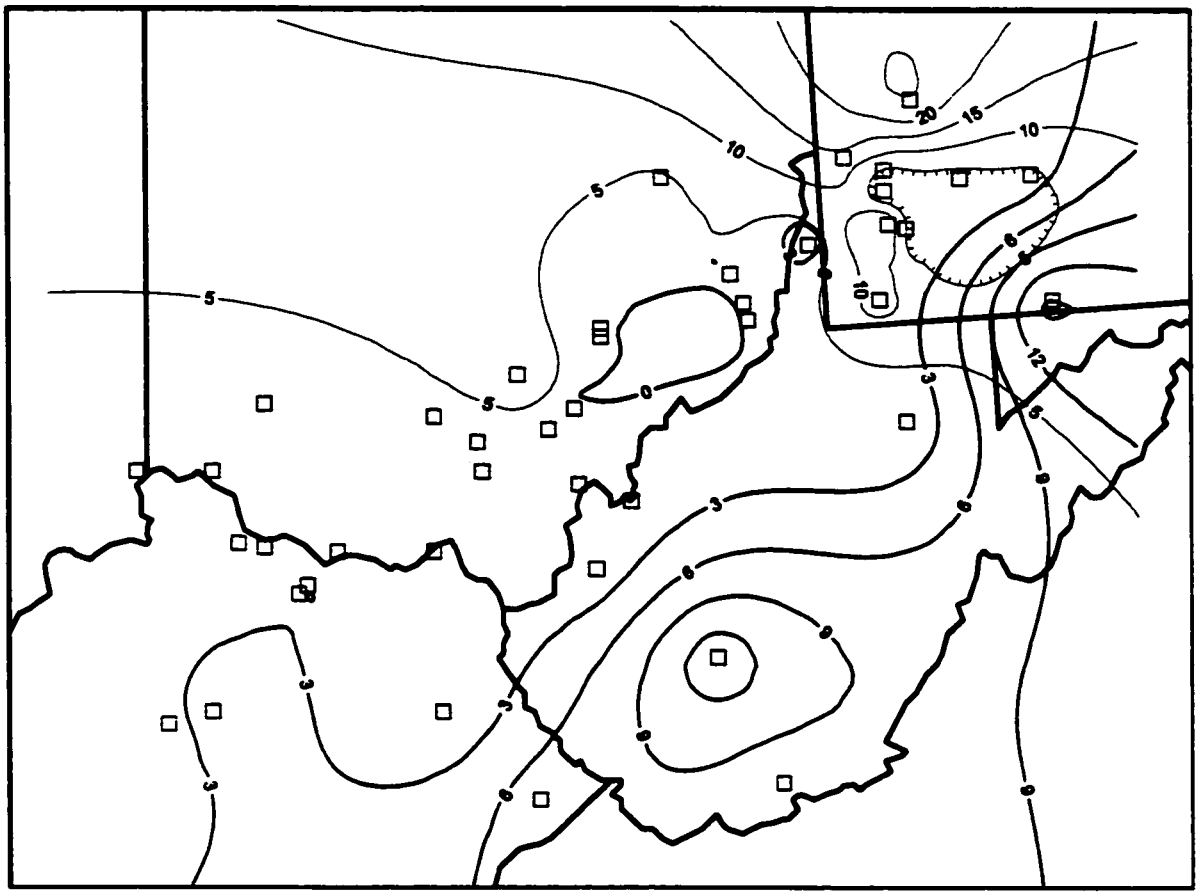


Figure 21. **Geographic distribution of deer (% NISP) in Ohio Valley assemblages.** ✚ indicates locations of poorly-preserved assemblages removed from analyses. Data are presented in Appendix B.

and bear to Late Prehistoric faunal assemblages may have varied with local environmental situation; elk prefer open-woodland upland habitats and bear prefer heavily-forested, topographically-rough situations. In Figure 22, I show the geographic distribution of the relative abundance (% NISP) of elk and bear across the study area, excluding the five previously-excluded poorly-preserved assemblages. Clearly, there are some broad differences in the way these resources

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contributions of animals to the subsistence system. Because of those criticisms, NISP is the counting unit used in this research.


20
15
10
10
5
5
5
0
5
5
5

turkey bones (Figure 23) was found to differ in middle Ohio Valley assemblages from pre-farming (A.D. 400 – 900) and post-farming (A.D. 900 – 1250) contexts (U = 3.000; p = .001). A Levene's test for homogeneity of variance indicated that the frequency of turkey bones also differs between post-A.D. 900 assemblages and earlier ones (F = 9.994; p = .007). This is probably due in part to the greater overall abundances of turkey remains in later assemblages. The greater exploitation of turkey during the early Late Prehistoric period may reflect their higher abundances in habitats created by swidden farming.

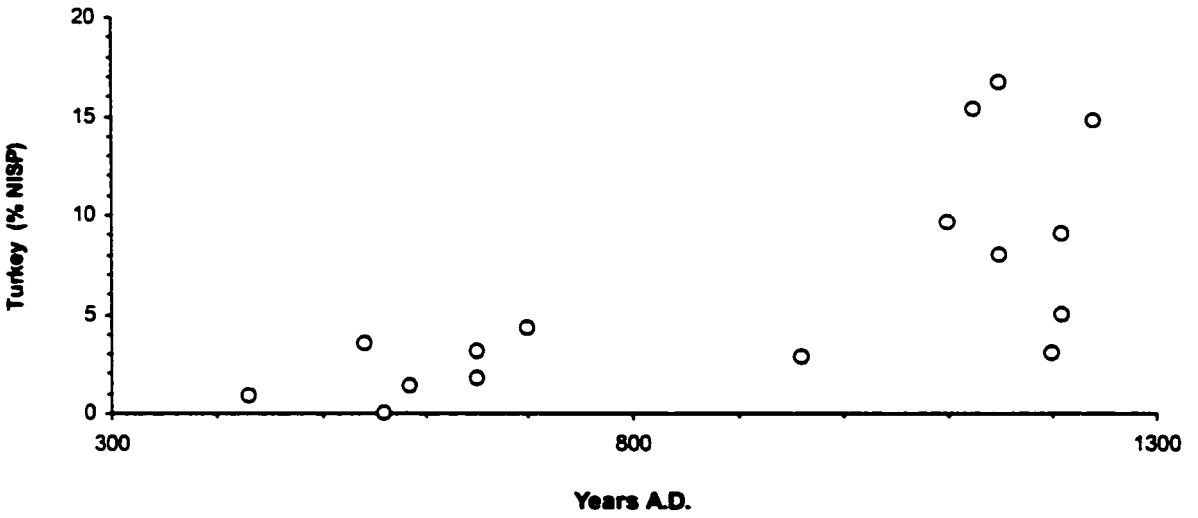


Figure 23. **Relative abundance of turkey remains in middle Ohio Valley assemblages dated A.D. 400 – 1250.** Data are presented in Appendix B.

There are other aspects of the Ohio Valley archaeofaunal record which could be explored, but the point of this discussion is to describe the basic character of the record of faunal exploitation in the study area as it is currently known. Faunal assemblages across the region have much in common, but they also display considerable variation, particularly with respect to local environmental situation. As farming systems spread, though, ecological landscapes surrounding

settlements became increasingly similar and the structure of resource exploitation apparently did so as well.

THE STABLE CARBON ISOTOPE RECORD

In one of the first applications of isotope chemistry to questions about prehistoric diet in the Eastern Woodlands, and using skeletal samples from four populations from the study area, van der Merwe and Vogel (1978) demonstrated significant differences in maize consumption between populations of the Late Prehistoric and earlier periods (Figure 24). Specifically, Archaic and Woodland populations did not consume isotopically measurable amounts of maize in their diets, while diets of individuals from contexts postdating A.D. 1000 apparently were dominated by maize. This finding was subsequently refined by Bender et al. (1981) using additional populations from the midcontinent, including samples from two populations in the Ohio Valley.

Stable carbon isotope studies since then have concentrated on establishing the relative degree to which various Late Prehistoric groups in the region were committed to maize as a dietary staple.[10] Although sometimes hampered by small size and/or relatively uneven coverage, these studies nevertheless have demonstrated a high commitment to maize during the Late Prehistoric period with significant temporal and environmental variation. When viewed as a set, several interesting observations about dietary variation can be made.

First, it is clear that an immense change in $\delta^{13}C$ values consistent with increased maize consumption occurred sometime between A.D. 400 and 1050. Unfortunately, there is a huge gap in the temporal distribution of $\delta^{13}C$ values during

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[10] Figure 24 includes all available stable carbon isotope ratios for the middle and upper Ohio Valleys, except for the 12 values reported by Sciulli (1995) that lack documentation as to how those data were generated.

the critical time, and thus we cannot say how or when that change happened. Although most researchers assume that the change happened gradually, that need not be the case. At any rate, without information on the timing and tempo of dietary change, explaining how and why it happened is impossible. Also of interest regarding temporal variation in $\delta^{13}C$ values is the hint of decreased maize consumption after roughly A.D. 1400; such a trend is also suggested by the maize ubiquity data of Figure 17.

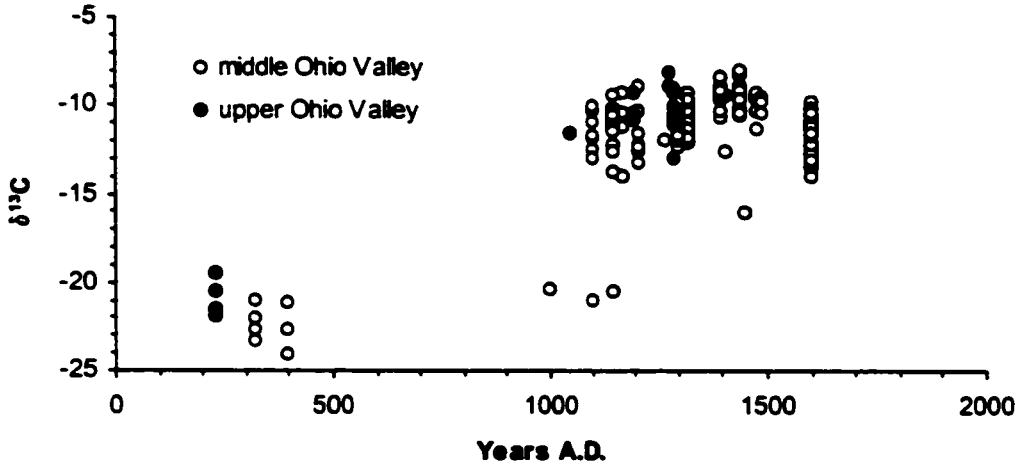


Figure 24. **Previously-collected stable carbon isotope evidence for maize consumption in the middle and upper Ohio Valley.** Data from Bender et al. (1981), Brashler and Reed (1991), Broida (1983), Conard (1988), Farrow (1986), Greenlee (1990), Hemmings (1977), Maslowski (p. c.), Schurr (1998), Schurr and Schoeninger (1995), and van der Merwe and Vogel (1978).

Second, the status of the three nonmaize consumers plotted in the range A.D. 950 - 1150 is particularly interesting. One of these individuals has been dismissed previously as reflecting an inaccurate ^{14}C date (Shott 1992) and the other two were assumed, based on their depleted ratios, to be associated with earlier occupations at their locales than the rest of the populations analyzed (Schurr and Schoeninger 1995). If the temporal assignments shown here are correct, however, this has implications for our understanding of dietary variation in the study area.

It suggests the presence of individuals not reliant on maize at a time when the apparent majority was exceedingly committed to the crop.

Third, Figure 24 shows that considerable variation in isotopic diet existed within and between Late Prehistoric populations in the region. Intracommunity variation is not explained by age at death or sex. Although some of the intracommunity variation may be due to temporal mixing (see above), other cases of individual outliers appear to reflect the incorporation of "foreigners" (i.e., people who were not raised with the burial population) into local groups (Dunnell, p.c.; Greenlee 1990).

Intercommunity variation in maize consumption may be explained partly by environmental circumstances. In a recent examination of the distribution of stable carbon isotope ratios in the lower and middle Ohio Valleys, Schurr (1998) found geographic patterning in mean $\delta^{13}C$ values from ten Fort Ancient and seven Mississippian settlements. He noted a northeast to southwest trend, with more negative means to the northeast in central Ohio, becoming more positive toward the southwest in eastern Kentucky and central Tennessee. He suggested that the isotopic variation reflects differential maize consumption that may be associated with the climatic limits of maize production, variation in environmental productivity, or some combination of the two, perhaps with other unknown factors. Following Schurr's lead, Figure 25 shows geographic variation in average $\delta^{13}C$ values for Late Prehistoric samples from middle and upper Ohio Valley locales. That populations from the West Virginia Panhandle plot in the same isopleths as those from the Kentucky Bluegrass suggests that isotopic diet is influenced by more than climatic conditions.

In earlier work, I found a significant negative correlation between the amount of arable land in the catchment area surrounding each settlement and the isotope ratios of the population residing there (Greenlee 1990). As the amount of arable land increased, the ratios became more negative, indicating lower levels of

maize consumption. Although initially counterintuitive, this relationship reflects the overall greater environmental diversity and productivity of broad floodplain locales versus the lower diversity of restricted locales. In some cases, maize farming probably allowed settlement in locations simply not productive enough to support a sedentary community on wild resources alone. Thus, catchment characteristics may be important in explaining spatial variation in isotopic diet.

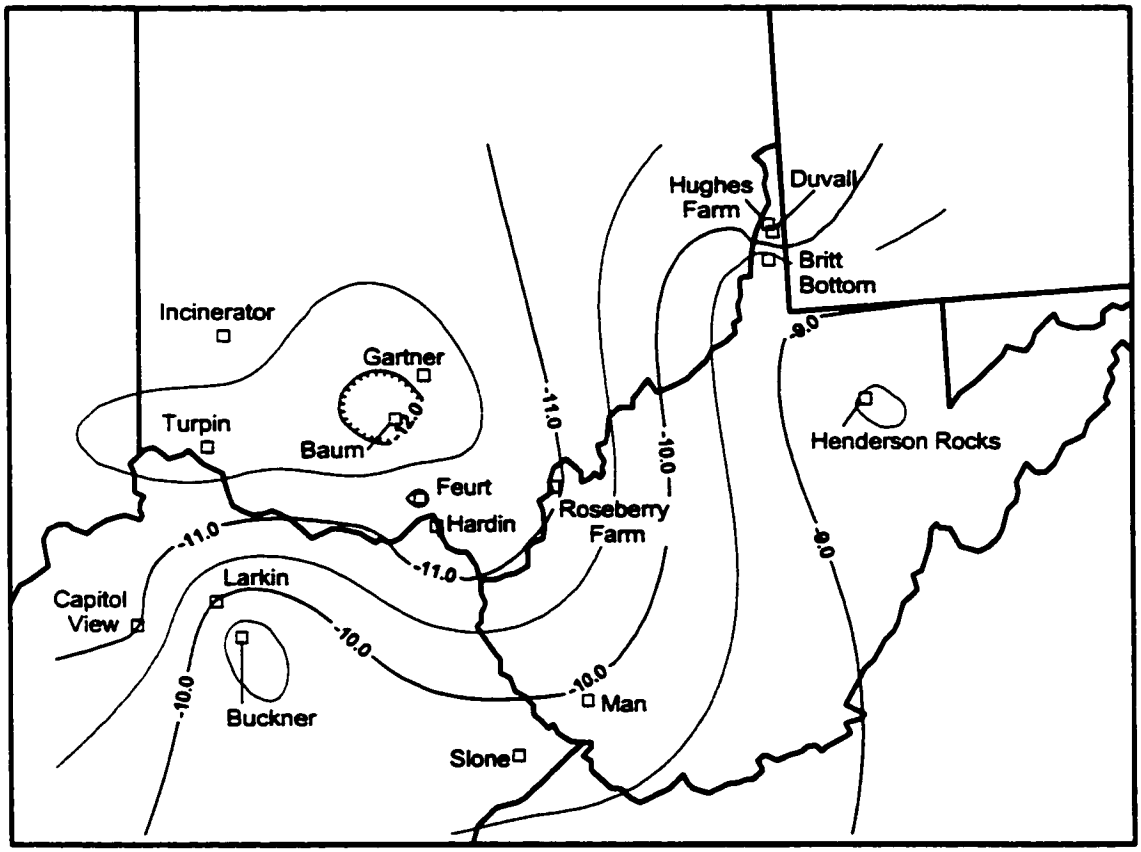


Figure 25. **Geographic distribution of average stable carbon isotope ratios in the middle and upper Ohio River valley.** Shown are Late Prehistoric locales with two or more contemporaneous individuals analyzed.

IMPLICATIONS

From this brief survey of the archaeological record of subsistence and diet in the Eastern Woodlands in general and in the middle and upper Ohio River

valleys in particular, it should be apparent that there is substantial temporal and geographic variation in the composition of subsistence systems across the region. Models that rely on gradual change across the region from gardening of Eastern Agricultural Complex plants to maize farming are not (uniquely) warranted by these data. An explanation of why maize farming appeared when and where and in what forms it did in the Ohio Valley must be able to account for apparently rapid and extreme changes in the subsistence record.

PREVIOUS EXPLANATIONS FOR SUBSISTENCE CHANGE

Attempting to explain the appearance, form and distribution of maize-based subsistence systems in the East is not a new endeavor. Although a multitude of causes have been proposed to account for the appearance of farming systems in general (e.g., Gebauer and Price 1992a: Table 1), most hypotheses can be subsumed under one of four broadly different categories: climate, demography, resource and/or technological availability, and social context.[11] Accordingly, changes in these variables resulted in conditions that were conducive to foraging/gardening people becoming farmers. As the following examples will make clear, no single variable can account for all aspects of subsistence change with respect to the appearance and spread of maize-based farming systems in the Eastern Woodlands (cf. Fritz 1990; Scarry 1993). Indeed, scenarios forwarded to account for any given instance of subsistence change often rely on more than one variable in a complex web.

CLIMATE

Although revealing little intellectual relationship to the works of Pumpelly (1908) or Childe (1939), climate is still considered to be an influential

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[11] It is interesting to note that these same four causes have also been used to account for the appearance of sedentary (Hitchcock 1982) and nucleated (Church 1987; Fuller 1981) settlements.

factor in the form and distribution of subsistence systems in the Eastern Woodlands. This position relies on the empirical connection between climate and plant productivity. In warmer, wetter years, productivity is good and environmental carrying capacity is high; in cooler, drier years, productivity is poor and environmental carrying capacity is low. Although there is no evidence for major climatic change in this region during the Late Holocene, there is reason to believe variation of a more subtle nature occurred. Indeed, climatic conditions have been invoked, through their impacts on subsistence, to account for several aspects of the archaeological record of eastern North America.

Climatic change and its impact on crop yields has long been considered a possible factor in the "collapse" of the Middle Woodland Hopewell phenomenon and the appearance of Late Woodland adaptations (Griffin 1960, 1961; Vickery 1970). As originally proposed, the onset of colder and drier conditions around A.D. 300 resulted in a shorter growing season, which in turn led to decreased productivity of the agricultural (specifically, maize) subsistence base that was assumed to support the Hopewell phenomenon. Even though we now know Hopewell populations were not dietarily dependent upon maize (Bender et al. 1981), climatic change could have delivered a similar blow by decreasing the net productivity of any key resource or set of resources.

Dunnell and Greenlee (1999) found, in their evaluation of hypotheses regarding the "collapse" of the Hopewell phenomenon, that the decline of cultural elaboration and the appearance of nucleated sedentary settlements at the beginning of the Late Woodland period were indeed correlated with climatic change. The nature of this climatic change, however, was not in the direction hypothesized by Griffin and the others. Using beach ridge data from the Upper Great Lakes and tree ring records from the Southeast to help resolve ambiguities in established climatic models, they found that climatic conditions apparently became warmer and wetter around A.D. 400. This change would have increased the productivity of local

resources; under conditions of higher carrying capacity, the fitness of waste (i.e., energy expenditure that does not increase the immediate survival or reproduction of organisms [Dunnell 1989; Kornbacher and Madsen 1999; Madsen 2001)]) was reduced and the cultural elaborations that were the hallmark of the Hopewell phenomena decreased.

Hall (1980) outlined the potential role of climate in his account of the development of complex social structure at Cahokia, located in the American Bottom, during the Late Prehistoric period. Specifically, he cited evidence for a warmer and drier weather pattern ca. A.D. 1160 – 1200 that made farming well-drained upland soils less reliable and led to increased competition for better-watered bottomland soils. This resulted in the congregation of higher population densities around those bottomland "oases," and an increased commitment to maize farming as wild resources were depleted. This episode of decreased resource availability was alleviated by the development of a complex social organization that facilitated both ceremonial and economic interactions among populations. That kind of social organization was no longer necessary when cooler, more humid conditions returned ca. A.D. 1400 and as a consequence, Cahokia was depopulated.

Along the same vein as his scenario regarding the Hopewell "collapse," Griffin (1961) suggested that an episode of deteriorating climate (cooler, probably moister, and with a shorter growing season) occurred ca. A.D. 1200 – 1700 and triggered changes in subsistence and settlement throughout the upper Mississippi River valley and the Plains. The suggested changes include decreased reliance on farming and increased emphasis on hunting among the upper Mississipi Valley populations, and in the Plains, a retreat into major stream valleys to the south, east and north along the margins of the Plains. This climatic episode was roughly coincident with that identified by Hall (1980) as responsible for the "decline" of Cahokia.

In his examination of middle Ohio Valley settlement variation during the Late Prehistoric period, Graybill (1981) linked changes in the settlement record with the impact of deteriorating climatic conditions on subsistence. Specifically, he noted a correlation between the reorganization of settlements into fewer, larger, geographically-constricted villages and an increasingly cooler and drier climate after A.D. 1200. Graybill suggested that the impact of that climatic change on subsistence systems of the middle Ohio Valley was probably not significant; however, the deteriorating climate probably wreaked havoc with not only the crops, but also the wild resources, used by populations farther north. In response, those groups expanded their exploitation territories southward. He argued that settlement changes in the middle Ohio Valley were a response to increased competition for resources with those more northerly groups and that competition was ultimately triggered by climatic change that affected the food supply available to those northern populations.

Johnson et al. (1989, cited in Hart 1993) also suggested that the impact of climatic deterioration on crops caused changes in the post-A.D. 1250 settlement record of the upper Ohio Valley. At that time, settlements became geographically constricted, larger in size, and more frequently situated in upland settings. They noted that those villages were located geographically in areas currently characterized by longer frost-free seasons and that they were found in topographic settings that permitted frost drainage. By situating their villages and, more importantly, fields as such, they minimized the impact of the deteriorating climate on their subsistence base. Johnson (1998) further noted an increase in semi-subterranean storage features ca. A.D. 1500 that he interpreted as an indicator of increased storage as insurance against more frequent crop failures associated with deteriorating climatic conditions.

Richardson and Anderson (1999) have recently reviewed evidence for climatic changes that may have contributed to a further geographic restriction of

upper Ohio Valley populations in the late 1500s and to the abandonment of southwestern Pennsylvania and adjacent West Virginia by those populations in the early 1600s. In particular, they noted that tree-ring records indicate two episodes of particularly severe drought conditions in the eastern United States that appear to be correlated with geographic redistribution and abandonment in the archaeological record. Historic documents that described the costs of comparable drought events for Ohio Valley populations were cited to support the potential devastation that the prehistoric droughts might have imposed on subsistence resources.

DEMOGRAPHY

"Population pressure" is a commonly cited variable in general accounts of subsistence change, particularly when dealing with the appearance of farming systems. Changes in the demographic structure of populations exploiting a region, particularly increases in population size and density, can lead to territorial infringement and reduced resource availability (Binford 1968; Boserup 1965; Cohen 1977; Johnson and Earle 1987; Rosenberg 1998a). Accordingly, plant cultivation is often presented as one solution to changes in food availability associated with increased population size and/or density. Demographic "pressure" has been proposed as a hypothesis to account for subsistence variation in three ways: (1) resource depletion, (2) intergroup competition for resources, and (3) intra- and inter-group cooperation.

Resource Depletion

In his examination of the archaeological record in the central Tombigbee River valley (western Alabama) during the Late Woodland and early Late Prehistoric periods, Welch (1990) explained the appearance of maize farming as a response to "subsistence stress" caused by increasing population density. Faunal assemblages of the late Late Woodland period contain less deer and higher frequencies of small taxa than earlier in the Late Woodland period. These classic

signs of faunal resource depression (Broughton 1995) are accompanied by increasing levels of nutritional stress and decreasing age-at-death statistics in associated human skeletal remains. In contrast, assemblages of the early Late Prehistoric period, to which maize is a significant contributor, show increased exploitation of deer and decreased exploitation of smaller taxa; animal size also increased within prey classes. The incidence of nutritional stress markers in human skeletal remains decreased and age-at-death increased. Welch (1990) argued that, by committing to a maize-based subsistence system, people reduced pressure on exploited faunal resources. Although he emphasized the notion that, with a maize subsistence base, hunters could concentrate on acquiring larger prey, it may also have been the case that decreased predation and/or landscape alteration allowed prey populations to rebound. The abundance of larger prey classes (e.g., deer) may have increased and within prey classes, animals may have lived longer, long enough to reach those larger sizes.

As part of Scarry's (1990) explanation of the appearance of complex societies in the Fort Walton area (northwest Florida), he also emphasized the impact of increased population density on the wild resource base as a key variable in accounting for subsistence change. As population density increased, limited resources were exploited more intensively; wild resources became harder to find in the local catchment, search and transport costs increased, and returns declined as the population began exploiting smaller animals and less productive plant stands. Once the costs of exploiting wild resources exceeded those of growing maize, which was at the time a minor crop, the latter became economically advantageous. The environmental changes that accompanied this increased commitment to maize farming served to further increase the costs of wild resources and decrease the costs of agricultural products.

Competition

Warfare has been suggested as an alternative explanation to the climate-oriented scenario[12] of Johnson (1998) for the prevalence of villages in upland situations in the Upper Valley during the Late Prehistoric period (George 1974, 1978a, 1983b, 1995; Mayer-Oakes 1955b). The notion that such villages are consistent with defensive posturing is seemingly supported by the high frequency of palisades (often accessorized with overlapping entries and bastions) and the occurrence of multiple, violent deaths (Blitz 1988; Milner 1995). Conflicts over land for maize cultivation and, to a lesser extent, wild resources are the most common reasons given for the appearance of defensive strategies. George (1974) argued, based on ethnohistoric accounts and assumptions about the productivity of upland soils, that cornfields were not located adjacent to the upland settlements, but were instead left untended in distantly-located floodplains. If this was true, and there is no compelling reason to believe it was,[13] then competition over resources would seem an unlikely cause of the hostility since the main dietary staple, located at some distance from the village, would have been left unprotected (or protected at very great cost) from predators. At any rate, the impact of these defensive tactics on subsistence was not clearly stated.

Only one study has attempted to evaluate directly the potential impact of intercommunity competition on subsistence. In an evaluation of published and unpublished stable carbon isotope data from the middle and upper Ohio Valleys, I (Greenlee 1990) found that the isotopic composition of individuals who

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[12] Johnson (1998) does not deny that some warfare did occur among Monongahela communities and that some upland locations may have been selected for defensive purposes; he notes, though, that the upland villages are consistently located adjacent to productive soils and in situations with air flow patterns that would minimize crop damage from killing frosts.

[13] Although early Euroamerican and contemporary farmers using permanent field strategies regard valley soils as agriculturally superior, upland soils were certainly adequate for maize cultivation, especially in swidden systems.

lived in settlements surrounded by palisades was significantly less negative, indicating greater dietary commitment to maize, than among those who lacked palisades. To the degree that palisades reflect intercommunity competition, this finding suggests that competition did have a significant impact on subsistence. Under competitive conditions, the collection of wild C_3 resources was reduced (because of the greater risks and/or higher costs involved in acquiring those more distant and scattered resources) and greater reliance was placed on highly productive maize crops (which could be grown in plots located near the settlement).

Intra- and Inter-group Cooperation

Although increased population density can lead to intragroup conflict (e.g., Hames 1983; Jochim 1981; Lee 1972; Rosenberg 1998a), it can also provide a large, conveniently located, labor pool (Fuller 1981; Hames 1983; Jochim 1981). The benefits of a labor force available for farming activities such as clearing fields, planting, maintaining, protecting and harvesting crops (Pollack and Henderson 1992) or for hunting activities like driving deer (Waselkov 1978) are easily appreciated. Subsistence efforts can be more efficient when more people are available to shoulder the workload.

Sharing among group members or between groups when resources are limited (Kaplan and Hill 1985; Kelly 1995; Minnis 1985; Sahlins 1972) is also an aspect of increased population density that may affect subsistence systems. Hart (1993) emphasized cooperative behaviors in his attempt to meld the climatic and defensive hypotheses for the upland locations of many Monongahela villages. He suggested those villages represented efforts by the population to mitigate both environmental and social risks. By "environmental risks," he meant decreased reliability of agricultural yields due to climatic variation; by "social risks," he apparently meant hostilities between groups, perhaps due to competition over choice locales and/or resources. Hart argued that, as populations grew, social risks increased; in response, reliance on agricultural products intensified and storage

increased in importance. Maize was cultivated in, and other resources were harvested from, a variety of upland and lowland settings in a divided-risk strategy (cf. McCloskey 1976; Winterhalder and Goland 1997). Redistribution networks (involving trade or exchange between different communities) worked to offset seasonal or annual variation in resource productivity.

Similarly, Ford (1974, 1977) noted that as dependence upon maize farming increased, so did the impact of crop failure on the farmers. Although raiding was one approach toward stocking empty larders when crop yields were low, he believed that it was unreliable.[14] He suggested that an alternative, and more dependable, solution might have involved the establishment of rituals whereby food could be redistributed in a controlled manner throughout the population (Ford 1974, 1977). Ceremonies dealing with maize planting, fertility, and harvesting may have acted to bring communities together and redistribute resources, thereby eliminating competition between communities created by the unequal distribution of resources.

Available Resources and Technology

As suggested by Figures 21 and 22, the composition of subsistence systems is influenced by the abundance and availability of local resources; thus, any explanation of subsistence variation should consider the particular combinations of physiography and ecology which form the background within which those subsistence systems operated. Changes in the abundance or diversity of resources exploited (due to nonclimatic factors such as the introduction of new resources,

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[14] Ford did not explain why raiding would be unreliable. In addition to obtaining food and/or other resources, a successful raid would reduce the size of the competitor's population. An unsuccessful raid would not only not produce new resources, but it might also reduce the size of the raider's population, perhaps increasing the likelihood of retaliatory raids. That it is a commonly-documented phenomenon during the historic era (e.g., Brandão 1997; Chagnon 1983) suggests that in some circumstances, at least, raiding must increase fitness among practitioners.

changes in the phenotypes of resources, or the development of new exploitation and/or storage technologies) have been argued to underlay the appearance of specialized farming systems.

Introduction of New Resources

As mentioned earlier, Wagner (1987) noted the apparent relative homogeneity (in terms of row number, row shape and kernel shape) of maize remains in middle Ohio Valley archaeobotanical assemblages and surmised that it reflected cultivation of a single variety, Eastern Eight-Row, over most of the area. She and others (e.g., Watson 1988) further speculated that this variety was introduced from elsewhere, perhaps the northeastern United States, where it had become adapted to cooler conditions and a shorter growing season than characterized other maize varieties. Thus, although maize had been present in the Ohio Valley since the Middle Woodland, it was not until this new variety was introduced into the area ca A.D. 800 that maize farming really took off.[15] Riley et al. (1990) further suggested that, in roughly A.D. 1300, Eastern Eight-Row spread westward, was introduced into the Mississippi Valley, and joined the higher-rowed maize varieties there (after the hypothesized climatic shift to cooler, wetter conditions and a shorter growing season that was correlated with the Cahokian "decline"). Hall (1980) stated that beans may have diffused westward across the Prairie Peninsula as a complex with Eastern Eight-Row maize.

Phenotypic Change in Resources

Probably the best example of phenotypic change in a resource accounting for some aspect of Woodland subsistence is provided by Cowan's (1997) analysis of squash remains from eastern Kentucky rockshelters. Of relevance here is the observation that squash from Late Woodland deposits had thinner rinds than

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[15] That archaeologists working elsewhere in the Eastern Woodlands (where higher-row-numbered cobs prevail) find this an unlikely scenario (Fritz 1992; Scarry 1993) does not in any way exclude it as a possible explanation for the Ohio Valley.

in Early Woodland contexts. Cowan suggested that the thinner rind signals a fleshier, more edible fruit than previously grown. Coincidental with this structural change in squash was a substantial increase in the frequency with which remains are found in deposits of that age.

In their account of Late Prehistoric subsistence change in the American Bottom, Rindos and Johannessen (1991) suggested that the sudden and widespread appearance of maize in the archaeobotanical record may have been prompted by the development of a storable variety of the high-yielding plant. During the Middle and early Late Woodland periods there, archaeobotanical evidence indicates that starchy seeds (maygrass, goosefoot, and knotweed) provided the subsistence base. At roughly A.D. 750, maize remains began to appear in significant numbers throughout the area, indicating widespread adoption of the plant. Because maize was in the area long before this event, they surmised that a change in some characteristic of the plant itself (like storability) best explains why it suddenly became an important part of the subsistence system.[16] Maize does not replace the starchy seed complex there, however, as the latter remains a major contributor to these assemblages until the late Late Prehistoric period; they inferred that this new form of maize was simply added to the existing agricultural system.

In their general model for the appearance of maize farming in the Eastern Woodlands, Keegan and Butler (1987) stated that the initial addition of maize to existing gardening systems during the Woodland period indicates a simple expansion of diet breadth. As population density increased due to growing populations and geographic circumscription, populations placed increasing emphasis on gardening. From a microeconomic perspective, gardens are large,

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[16] Lopinot's (1992) identification of maize as an important, *storable* resource for populations of the American Bottom by the late Late Woodland period is consistent with this contention.

centrally-located patches that present decreased search/transportation costs and increased return rates. As a consequence of increased gardening, diet breadth decreased and one or a few crops were emphasized. Over the few hundred years that maize was a minor crop, phenotypic changes toward an increased return rate (higher productivity and greater harvest efficiency) had occurred (see also Hall 1980) and maize became the dominant crop. Although this scenario has elements of the demographic explanation described previously, Keegan and Butler argued that, by emphasizing how and why maize came to dominate the subsistence system, their account is fundamentally different.

New Technologies

Hart (1995) noted changes through time in the construction of semi-subterranean storage facilities among Late Prehistoric populations of the upper Ohio Valley. Storage, of course, is one way of compensating for predictable food shortages during seasons of low resource availability (Halstead and O'Shea 1989a; Jochim 1981; Smyth 1989; Testart 1982) and is a fundamental characteristic of farming systems. Because many early Late Prehistoric occupations apparently lack identifiable storage facilities, Hart concluded that stored agricultural products were not a significant resource for those communities. Many middle Late Prehistoric locales had storage facilities and they were often attached singly to domestic structures, suggesting that stored agricultural products were becoming more important in the subsistence system. The appearance of structures with multiple attached storage facilities, called petal structures, in the late Late Prehistoric period, was interpreted to reflect changes in both subsistence and sociopolitical organization. While he did not state specifically that changes in storage technology *caused* subsistence change, Hart implied that variation in storage facilities reflected (and perhaps facilitated?) subsistence variation.

For many areas of the Eastern Woodlands, including the Ohio Valley, bow and arrow weapon systems, as indicated by the morphology of the projectile

points, was probably introduced during the Late Woodland period (Blitz 1988; Hall 1980; Muller 1986; Seeman 1992; Shott 1990a, 1993, 1997). A recent analysis by Nassaney and Pyle (1999) reported that the introduction and adoption of bow and arrow technology was more variable both temporally and geographically than earlier models posited. Although most researchers assume that the adoption of this new weapon system would have substantially increased hunting efficiency, that it did not rapidly and completely replace previous weapon systems suggests that the old technology was superior for some resources (e.g., large prey) (Shott 1993). At any rate, it is often supposed that the appearance of the bow and arrow should have had a significant impact on subsistence systems. Faunal assemblages in some areas of the East do not show obvious changes associated with the appearance of the bow and arrow (Blitz 1988); the impact of changes in hunting technology on Ohio Valley faunal exploitation has not been addressed. Some researchers (e.g., Blitz 1988; Nassaney and Pyle 1999) have suggested that the bow and arrow might have been adopted as a particularly effective weapon for warfare.

SOCIAL CONTEXT

Although the need for defense could be argued to be a "social" problem (thereby presenting considerable overlap with the demographically-oriented explanations described above), scenarios which evoke social factors are generally not concerned with the effects of population density. Instead, they emphasize the appearance and spread of farming systems through contact with other groups (via diffusion, migration or acculturation), internal sociopolitical reorganization, or symbolic/ritual/ceremonial uses for resources.

Outside Influence and Population Intrusion

Our understanding of the appearance of maize farming has changed considerably from those earlier times when archaeologists believed maize farming was brought, along with other traits, from Mesoamerica; or, later when it was

believed that at least the idea of farming had diffused from there (cf. Caldwell 1971). Even when it was accepted that farming was probably an independent development in the Eastern Woodlands (in other words, an analogous, not homologous, similarity), archaeologists clung to the notion that it was a development of populations living in the Mississippi River valley; accordingly, it spread throughout the East from that Mississippian source via migration, diffusion, and acculturation (Caldwell 1971). Which of those different mechanisms was primary in any particular case depended upon the actual degree of contact believed necessary to account for the suite of traits that Mississippian and the receiving populations had in common at any particular time. Economic systems were just one of many traits that could be passed from one group to another.

Griffin (1943) was the first to explicitly consider the Fort Ancient phenomenon of the Middle Valley as a "Mississippified" product, i.e., it owed many of its attributes to influence from populations of the Tennessee, Mississippi and lower Ohio Valleys. He considered early Fort Ancient to be a result of the diffusion of ideas, while later developments involved actual migrations of people and acculturation of the local populations (cf. Essenpreis 1978). Although Griffin may have been the first, Prufer and Shane (1970) were the strongest proponents of the argument for an influx of Mississippian populations into the Ohio Valley. In their examination of early Fort Ancient villages in the Scioto River valley, they cited abrupt differences in site location and material culture between Late Woodland and Late Prehistoric occupations as evidence for a direct invasion and replacement by Mississippian populations. Surviving local populations were believed to have relocated into the outlying hills.

Even as early as 1943, Griffin (1943) considered the idea that Late Woodland phases like Intrusive Mound, and then later Newtown (Griffin 1952), might be local sources for many attributes of Fort Ancient. Griffin apparently rejected those ideas then, as did several scholars (e.g., Morgan 1952; Willey 1966).

They all implied that Mississippian migrations were mostly responsible for middle Ohio Valley developments. Recently, however, Griffin (1993) has suggested that this notion is a misinterpretation of his earlier statements – that, while the presence of some traits probably is the result of contact with other groups (cf. Cowan 1986; Drooker 1997), the Fort Ancient phenomenon is largely an *in situ* development. There is now ample evidence of local Late Woodland-aged precursors to most Fort Ancient traits, thus demonstrating both stylistic and functional continuity (Barkes 1982; Brose and White 1983; Church 1987; Essenpreis 1978; Graybill 1984; Griffin 1978; Rafferty 1974).

Similar to the Fort Ancient case, archaeologists initially believed that the Monongahela culture was the result of a "Mississippian intrusion" merging culturally with local Woodland groups (Dragoo 1955; Mayer-Oakes 1955b; McMichael 1968). The observation that Monongahela populations of southwest Pennsylvania and northern West Virginia are more similar to their local Woodland populations than the Fort Ancient populations of the middle Ohio Valley are to theirs does not support the notion of a Mississippian migration and population replacement, however. Dragoo (1955) felt the influence of the Mississippians was reduced in the Upper Valley, relative to the Middle Valley, due to the presence of the Iroquois to the northeast. McMichael (1968) believed that the intrusion simply lost momentum with distance from the Mississippi Valley. More recently, though, Johnson (1998) has made the case, primarily on the basis of ceramic attributes, for diffusion of some traits from the Middle Valley and continuity, not replacement, among Upper Valley populations.

There is some clear evidence for significant migrations of people in the Eastern Woodlands during the Late Prehistoric period. The Mississippian outposts of Aztalan and Steed-Kisker are some well-known examples (Griffin 1967; Setzler 1940). People may have entered the Ohio Valley from northwestern Pennsylvania and north-central Ohio during the late Late Prehistoric period, as

well. Ceramic assemblages, in particular, from several Upper Valley locales (e.g., Bonnie Brook, Johnston, McJunkin, McKees Rocks) show nonlocal characteristics (Buker 1968; George 1995, 1997; Johnson 1976, 1998). Similarly, artifact assemblages at a few Middle Valley locales (e.g., Riker, Neale's Landing) may evidence the entrance of groups into the area (Brose 1994; Graybill 1981). Even so, these migrations have not been shown to have impacted subsistence.

In the Ohio Valley, Dunnell (1972) identified both stylistic and functional discontinuities in the archaeological record of the Fishtrap Reservoir area of mountainous eastern Kentucky. The lack of developmental, transitional elements between Archaic and Fort Ancient components in the area led him to argue that the Late Prehistoric presence there is locally intrusive. Temporary hunting camps provide some evidence that populations of adjacent areas were familiar with the region through their use of it as a hunting territory. The high yields of maize crops grown on the tiny floodplains along the river may have allowed sedentary settlement in a situation where it could not be supported using only wild resources or EAC plants. Dunnell suggested that Fort Ancient groups might have migrated into the area along the Levisa Fork of the Big Sandy River.

Social and/or Political Reorganization

Bender (1985) and others (Hayden 1992; Johannessen 1984) have emphasized the role of increasingly demanding social interactions as causal in the intensification of food production. Efforts by individuals and/or kin groups to gain prestige and build social bonds with other groups may have required the production of surplus food for the hosting of feasts and giving of gifts. Competition among individuals/groups to build prestige and establish more alliances may have resulted in increased pressure to reciprocate. Thus, food production requirements spiraled for reasons beyond "simple economic need."

In his account for the appearance of maize-based subsistence systems in the central and lower Mississippi River valley, Nassaney (1987) emphasized the

role of the developing Mississippian political organization in both requiring and facilitating intensive exploitation of resources. Because cultural developments (e.g., status differentiation, acquisition of exotic materials, and moundbuilding) preceded maize farming in those areas, the sociopolitical structure must have been a factor in the appearance of maize-based subsistence systems in this view. In particular, he suggested that a food surplus was necessary to support the political demands of the social elites; at the same time, the hierarchical structure of the culture provided the labor and a redistribution system that could meet those demands. Of the cultivated plants in the subsistence system, maize was the one with a productive capacity high enough to support the Mississippian sociopolitical structure.

Cultural Meaning and Rituals

Ethnographically, maize has been documented as a symbol for power, for fertility, for transformation, and for healing (Hastorf 1994; Hastorf and Johannessen 1994). Thus, some researchers believe that maize was more than simply a productive subsistence resource to prehistoric populations; it was probably a cultural symbol, as well. Accordingly, explanations of how and why maize farming appeared when and where it did and in what forms it did must go beyond the economics of subsistence to consider this symbolic dimension (Hastorf 1994).

Hastorf and Johannessen (1994) noted four features of the record of maize use in eastern North America (and elsewhere in the New World) that suggest to them that maize was more than just a crop: the "special" contexts from which early maize has been recovered, the apparent rapidity with which maize went from playing a minor to a major role in prehistoric subsistence systems of the East, the correlation of this change with social and political upheaval, and the observation that it is always maize (and not some other plant) that becomes the focus of specialized farming systems. Considering the archaeological record for the American Bottom, they found that change in "foodways" (involving an increasingly elaborate and variable ceramic inventory and increasing consumption of maize)

paralleled changes in the political and social aspects of life (Johannessen 1993b). They argued that maize, as a symbol of cultural identity, both reflected and was instrumental in effecting the social and political reorganization that was occurring (Hastorf and Johannessen 1994).

Along the same line, Scarry (1993) argued for a cosmological reason why maize, and not any of the native starchy-seeded plants, was the plant that eventually became the dietary mainstay for many populations of the Eastern Woodlands. According to Scarry, maize initially may have been considered a sacred plant. Individuals seeking power and prestige chose to emphasize maize production and consumption, thus symbolizing and cementing their own importance through their connection with that powerful plant. Although she does not take the scenario any farther, presumably as more people sought the power and prestige that growing and eating maize conferred, maize lost its status as a "special" plant and became a mainstay of the commoner diet, as well.

Rose et al. (1991) suggested that maize was initially considered by populations of the central Mississippi Valley as one aspect of the Mississippian lifestyle they were adopting from elsewhere. Because EAC plants and wild resources were so productive, the general population had no need for maize as a dietary staple. As such, maize was grown for and eaten only by certain individuals within ritual contexts. It was not until an increasing population density began to stress the subsistence system that maize became a dietary staple there.

Wymer also considered the evidence of a social role for maize in Ohio Valley prehistory (Wymer 1994). She identified several aspects of the Ohio Valley archaeobotanical record of maize use that are of potential social relevance: maize first appears only in mortuary contexts during the Middle Woodland period; maize remains are rarely recovered from early Late Woodland deposits and those fragments have a distinctive intra-site spatial pattern; and by the late Late Woodland period, maize remains are common and lack any spatial patterning.

From these observations, Wymer (1994) suggested that maize was perceived as a special plant and it was used in distinctive social contexts during the Middle and early Late Woodland periods. By the late Late Woodland, maize had become a dietary staple and was no longer given a special status among food resources.

To account for the apparent decision of Ohio Valley Late Prehistoric populations to "abandon" most native cultigens and many wild plants in favor of a less diverse maize-based diet, Rossen (1992) has suggested that maize might have had some religious or ceremonial significance. He and others (e.g., Fortier 1991, 1992; Heilman and Hoefer 1981; Prufer and Shane 1970) have offered the Green Corn ceremony (Swanton 1946; Witthoft 1949) as one example of the sort of ritual that might have been involved. Cedar (Parker 1992; Wagner 1987), tobacco (Parker 1992) and bear (Guilday 1961; Hallowell 1926; Lang 1968; Parmalee 1959) are other resources that have been suggested to be of potential religious or ceremonial significance to prehistoric populations in eastern North America.

Overview of Explanatory Attempts

Many of these "explanations" were developed within a post-hoc interpretive framework, i.e., a pattern was documented and a scenario to account for that pattern was advanced with little or no empirical testing. In addition to inattention to hypothesis testing, most scenarios suffer from one or more of several problems:

1. Variables lack empirical sufficiency (Lewontin 1974), i.e., they have no relevance in the archaeological record. Terms like "social risk," "resource stress," "prestige" and "cultural symbolism" have no empirical referents that can be observed and/or measured. Using such terms precludes hypothesis testing and consequently, scientific explanations of phenomena are not possible.

2. Explicit theoretical linkages are lacking. In the absence of explicit theory, it is not clear how variables are linked mechanically. Consequently, why some variables (e.g., warfare, sociopolitical development, cultural symbolism) should cause subsistence change, or why they should cause a particular trajectory of subsistence change, does not follow. It is simply presumed that people responded (in a way that seems "logical," i.e., reasonable in terms of our own cultural conventions) to a range of environmental situations, both natural and cultural, by changing their subsistence systems.

3. Correlation is treated as causation. Correlations between some variable (e.g., climate, settlement, or social organization) and subsistence change are often assumed to reflect a causal relationship without providing mechanisms of causality. Gould (1981) has called this one of the most common and injurious errors in science.

These problems make the current suite of scenarios unacceptable as scientific explanations of prehistoric subsistence change. A new approach is needed.

CONCLUSION

A review of the archaeological record of the Late Woodland and Late Prehistoric periods in the Eastern Woodlands (in general) and in the middle and upper Ohio River valley (in particular) reveals significant temporal and geographical variation in subsistence. That explaining this record of change remains more a goal than a product after several decades of research is affirmed by the diversity of arguments present in the literature today. Some of these scenarios may have an element of truth, but without reformulation so that testing is possible, we cannot know. The appearance, distribution and form of maize-based subsistence

systems are historical phenomena and thus their causes will vary from area to area. No global explanations can possibly account for the whole range of specific historic trajectories.

Chapter Three considers the problem from a different perspective, that of evolutionary theory. It reviews briefly evolutionary principles, data requirements, and explanatory structure and then addresses subsistence and diet in theoretical terms, with particular emphasis on the relevant archaeological parameters and their availability in the published literature. Finally, the traditional explanatory scenarios are "rewritten" from an evolutionary perspective and framed as testable hypotheses insofar as possible, and the kinds of data that are needed to test those hypotheses are identified.

CHAPTER THREE: SUBSISTENCE IN THEORETICAL PERSPECTIVE

The selection of a theoretical perspective from which to tackle the task of explaining the record of subsistence change outlined in Chapter Two is a critical step. Previous attempts at explanation have generally relied on common sense and disciplinary tradition, using poorly-defined units and post-hoc interpretation to make sense of the results. In essence, poorly-known (and presumably different) theories have been applied to different chunks of the archaeological record. The result is a series of scenarios that lack comparability and that are untested.

To know why things are as they are requires not only an explicit theory, but an explicit scientific theory of history. Theory determines what questions are asked, how they are answered, what observations are made, and how the results are evaluated and systematized. Scientific theories, in particular, provide standards to assess correctness (i.e., statements are testable) and integrate answers into a coherent body of knowledge. The only scientific theory that explains historical phenomena is Darwinian evolutionary theory (Dunnell 1982; Lewontin 1974; Popper 1964). Below, I outline the tenets of evolutionary theory briefly, followed by a consideration of some of the fundamental issues concerning the application of evolutionary principles to archaeological questions.

DARWINIAN EVOLUTIONARY THEORY

Evolutionary theory explains "change as the differential persistence of variability" (Dunnell 1980b:38). Change does not occur by gradual transformation of one variant into another; instead, evolution conceptualizes change as the alteration of frequencies of different variants.

Evolutionary change results from a two-step process (Gould 1983; Rindos 1989). The first step involves the generation of variation, of alternative conditions, that can be transmitted; the second step is sorting existing variation to produce changes in variant frequencies. Variation is critical to evolutionary change, because without it there is nothing to sort; or, as Rindos (1989:9) notes, variation "fuel[s] the engine of evolutionary change." For Darwinian theory to apply, variation must be heritable (i.e., it is transmitted from one organism to another) and it must be random (i.e., nondirectional with respect to selective conditions).

The development of genetics in the late 1800s provided evolutionists with a transmission mechanism, resulting in the "new synthesis" of the 1930s. The success of this intellectual marriage has led many to see one solely in terms of the other and vice versa (Provine 1971). Evolutionary theory does not require that transmission be restricted to genetic transmission, though. Variants can be transmitted among organisms culturally (i.e., learned), as well (e.g., Alexander 1974; Bonner 1980; Boyd and Richerson 1985; Dunnell 1978, 1980b). Indeed, cultural transmission is potentially a more significant source of change than biological reproduction because cultural transmission occurs more or less continuously, may involve considerably more organisms and has fewer biological constraints (e.g., reproductive life span). With cultural transmission, traits may spread more widely, more rapidly than with biological transmission. Leonard and Jones (1987) introduced the term "replicative success" to denote the differential spread of both cultural and biological variants regardless of how they are transmitted.

EXPANDING EVOLUTIONARY THEORY

Evolutionary theory developed in the context of nonhuman biology and, as a consequence, it exhibits many unnecessary conceptual restrictions and limitations. The expansion of evolutionary theory to explain all living phenomena has been underway for some time (e.g., Alexander 1979; Bonner 1980; Dunnell

1980b; Hamilton 1964; Leonard and Jones 1987). Complicating this expansion, however, has been the anthropological flirtation with cultural evolution and its conflation with scientific evolution. This has led to the invention of concepts and terms that sound like evolutionary ones (and are often mistaken for them, but which differ significantly from them), or to the reinvention of perfectly sound evolutionary ideas disguised by social science jargon. The implications of this, however, are that it is legitimate to treat extant, *ad hoc* explanations as potentially meritorious if they can be reconstructed in evolutionary theory and rendered testable.

Generation of Variation

Evolutionary biologists have identified several mechanisms responsible for generating variation, the first component of evolutionary change. Mechanisms such as mutation, recombination, gene-flow and migration produce alternative variants. Interestingly, anthropologists have recognized virtually the same mechanisms, albeit with new names and generally without theoretical rationale. Invention (Eckholm 1964; Steward 1929), the creation of wholly new traits, is a form of mutation; innovation (Barnett 1953; Ford 1962 [cited in O'Brien and Lyman 1998]), the rearrangement of existing variation to produce new traits, is a form of recombination; diffusion (Kroeber 1931; Meggers et al. 1965; Smith 1933), the movement of ideas from one population to another, is analogous to gene-flow; and migration (Petrie 1939; Rouse 1986) is the movement of populations.

Most evolutionists have little problem with the notion of undirected variation, as long as people are not the subject matter. Some archaeologists and evolutionary biologists have conceptual problems with undirected variation when applying evolutionary theory to people because they believe that our ability to solve problems provides direction to the variation at the least, and guides evolution at the most (Alexander 1979; Boone and Smith 1998; Childe 1939; Durham 1979; Gould 1980, 1981, 1987; cf. Dunnell 1980b; Rindos 1989). People are not the only

creatures that "solve problems" (Popper 1990). Such confusion arises when our own cultural background is inadvertently substituted for theory, conflating "reason" with "cause" (Dunnell 1989, 1992; Sellars 1962).

Sorting of Variation

The frequency of alternative variants changes as a result of sorting, defined traditionally as the "differential birth and death among varying organisms within a population" (Vrba and Gould 1986:217). Because transmission occurs both culturally and genetically, and because the replicative success of learned variants may not affect the birth and/or death rates of the individuals who possess them and vice versa, sorting must be viewed as differential replication in general. Any of several processes (natural selection, drift, etc.) operating at any of several scales (e.g., genomic constituents, organisms, groups of organisms, species) may cause sorting (Vrba 1989; Vrba and Gould 1986). Determining both the scale and the mechanism of sorting are empirical issues.

Natural selection is one process whereby direction and structure are imparted upon existing variation. Selection denotes the differential replicative success that occurs as a result of the articulation of variant individuals with their environment; mechanically, variants that increase the organism's fitness (the expected probability of replicative success) are transmitted successfully in greater proportion relative to those that do not. It is the phenotype, individual morphology and behavior, that is subject to selection (Dawkins 1982; Mayr 1970).

Although selection is frequently considered to be the most important, it is not the only mechanism responsible for sorting. Random sorting processes, known as drift, also influence trait frequencies. Mayr (1970) recognizes three sources of drift: (1) changes in the frequencies of variants resulting from accidents of sampling, (2) geographical variation in the frequency of traits in isolated populations due to the founder principle (where the number of variants is limited to those carried by the few original founders), and (3) random fluctuations in the

frequencies of variants that are selectively equivalent. One should not assume that all sorting is a result of natural selection; again, what sorting is due to selection is an empirical determination.

I want to clarify how evolutionary mechanisms of sorting can be distinguished. At the simplest level, identifying the probable mechanism requires that we distinguish between selectively neutral and non-neutral variants. Selectively non-neutral variants (functional *sensu* Dunnell 1978) are those which affect the cost or the performance of the associated phenotype; they are subject to natural selection and their frequency distributions in time and space are structured accordingly. Selectively neutral variants (stylistic *sensu* Dunnell 1978) are, as the name indicates, not subject to selection (Kimura 1979; King and Jukes 1969; Sober 1984) and they will have distributions that reflect stochastic processes (e.g., drift). Variants are not inherently neutral or non-neutral; a particular trait may be neutral under one set of circumstances and non-neutral under another (Dunnell and Feathers 1991). Both engineering analyses, which compare the production costs and/or performance of different variants, and distributional studies, which track the frequency distributions of variants through space and time, are needed to distinguish between neutral and non-neutral variants for any situation (Kornbacher and Wilhelmsen 2000).

Selectively non-neutral variants interact with the environment and impact replicative fitness. Consequently, the selective environment structures the spatial distribution of functional variants; higher frequencies of functional variants are associated with those environmental situations where they are selectively advantageous. Selectively neutral variants do not interact directly with the environment, nor do they impact replicative fitness; their spatial distributions are

random[17] with respect to environmental structure, except to the degree that the environment impacts the density of transmitters. In the temporal dimension, the frequency distributions of selectively neutral variants are stochastic, whereas non-neutral variants are not.

Based on the distribution of the variant in question at a particular place and time, either selection or a random mechanism can be posited to account for that distribution. Again, if the distribution is random, then it is not a consequence of selection; random sorting mechanisms such as drift or migration may be more appropriate. If the distribution is nonrandom, then it is not a consequence of random sorting mechanisms. In this case, selection is a more likely explanation, but the possibility of pleiotropy must be considered. If the variant in question is not known through engineering analyses to impact phenotypic function, and if it is structurally related to a variant that does affect function, then pleiotropy may be the best explanation (Sober 1984). If the variant does directly affect the cost and/or performance of the phenotype, then natural selection is probably responsible for its distribution. Increasing firing temperature may, for example, increase the hardness of a ceramic body, change its color from brown to red, and/or decrease permeability (Dunnell and Feathers 1991; Feathers 1990). One has to demonstrate which factors (hardness, color, permeability), if any, are under selection and to what degree. Correlations must be explained since they are, in and of themselves, descriptive only.

APPLICATION OF EVOLUTIONARY THEORY TO ARCHAEOLOGY

Much has been written about scientific evolutionary theory – how it differs from cultural evolution in the social sciences, its ontological position, its conceptual definitions, and its potential applicability to archaeological problems

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[17] "Random" is used here to mean "unpatterned" with respect to selective conditions and not statistically random (cf. Feathers 1990). Variants are not truly random because they are limited by functional and historical constraints (Popper 1990).

(e.g., Blute 1979; Broughton and O'Connell 1999; Dunnell 1978, 1989, 1992; Leonard and Jones 1987; O'Brien and Holland 1990; Rindos 1984, 1989; Teltser 1995) – and there is no need to rehash those statements here. I do, however, want to review the data requirements posed by a Darwinian approach to archaeological problems and outline the structure of evolutionary explanations in the archaeological context.

Data Requirements

The data requirements of an evolutionary approach to archaeology are largely consistent with those of any scientific endeavor. Even if they do not always treat such considerations as mandatory, archaeologists are already well-aware of data quality issues (e.g., taphonomy, sampling). An evolutionary approach to archaeology differs from most other archaeological approaches in its emphasis on measuring variation. Whereas modal data are adequate for many explanatory approaches, they are insufficient for an evolutionary archaeology. As noted in the preceding section, evolutionary theory explains changes in frequencies and variation, not differences in modes or kinds.

To illustrate the problem with modal data, consider Figure 26. Figure 26a plots a hypothetical change in mean stable carbon isotope ratio over time in some hypothetical study region. This plot is not unlike many drawn to illustrate changes in maize consumption through time in the Eastern Woodlands (e.g., Buikstra 1992; Buikstra et al. 1988; Smith 1989, 1992b; Stothers and Bechtel 1987; van der Merwe 1992). Figures 26b and 26c illustrate two different ways that the individual data points underlying the means of Figure 26a could be distributed. In Figure 26b, the data suggest the entire population underwent a gradual change in maize consumption through time; the data of Figure 26c indicate the presence of two populations, maize and nonmaize consumers, with some temporal overlap. With only modal data, the structure of the underlying data cannot be determined.

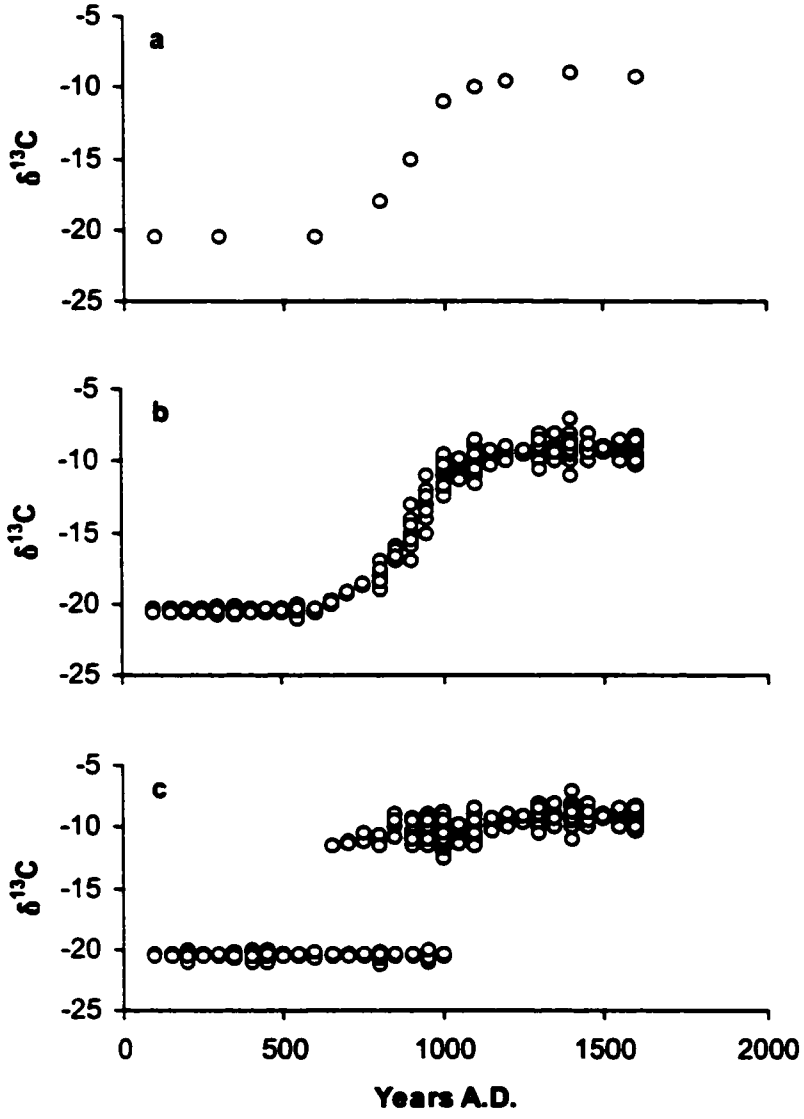


Figure 26. **Two models of change in isotopic diet through time.** (a) mean $\delta^{13}C$ against time. (b) and (c) are two distributions of individual $\delta^{13}C$ values, either of which could underlie (a).

A second reason why modal data are not appropriate for evolutionary explanations is that the distribution of variation can inform as to the sorting processes involved. Again, consider Figures 26b and 26c. The structures of these distributions are very different, one being gradual in appearance and the other

being punctuated (Eldredge and Gould 1972; Gould and Eldredge 1977). In Figure 26b, change occurs gradually across an entire population. In Figure 26c, change occurs in some part of the population and spreads, giving it a punctuated appearance. Since here we are dealing with a culturally-transmitted variant, diet, distinguishing between these two modes of change has implications for the mechanisms by which it is transmitted.

In addition, if we seek to conclude that two distributions are different or not, we must know what kinds of errors are involved in generating those data. Thus, along with the emphasis on documenting variation must come concern with sampling and measurement error. Although some researchers have been concerned with sampling issues (e.g., the relation between sample size and richness [Grayson 1989; Grayson and Cole 1998]) and others with measurement issues (e.g., analytical error [Greenlee 1996; Radosevich 1993]), they are in the minority.

Explanatory Structure

Although evolutionary change is a two-step process, generating evolutionary explanations is a three-step process. First, the relevant variation must be documented. This first step requires creation of units that are appropriate to the research question and that have empirical relevance. The second step involves generating testable hypotheses that involve specific evolutionary mechanisms to account for the patterns documented previously. To do so requires that the first step has been done with units that can be explained, i.e., units that occur in the theory (e.g., style and function). *Ad hoc* units, e.g., those that mix style and function, will not be explicable by evolutionary mechanisms (cf. Dunnell 1978; Hull 1980; Jelinek 1976). Finally, the hypotheses must be tested against the empirical record; hypotheses that are not falsified after testing are explanations until they fail. This last step involves an appeal to other variables beyond those described in the first step, including, where appropriate, engineering analyses to demonstrate functional relationships among variables. In terms of explanatory structure, then,

evolutionary approaches to the archaeological record stand apart from most traditional attempts. One can derive interpretations to account for any set of data; hypothesis testing requires empirical data generated specifically for that purpose.

The lack of substantive evolutionary applications in the archaeological realm is a result primarily of difficulties meeting the data requirements of the theory. First, until recently, most archaeological data had been generated under the culture historical approach. While the units of culture history were appropriate for its explicit goal, chronology, those same units are not likely to be appropriate for other uses. In most cases, previously-generated data are not in a format that can be explained by evolutionary theory. Second, testing evolutionary hypotheses demands immense, well-dated data sets that require great investments of time and money to acquire. Thus, to address a seemingly simple question in a scientific manner demands a much greater effort than required by most other approaches to the record and it is no surprise that archaeologists working within an evolutionary framework have not yet produced a complete product. That does not mean that the goal of explaining archaeological phenomena from an evolutionary perspective is unattainable, just that it will take longer to reach conclusions than with an interpretive approach.

There is another aspect of explanatory structure that needs to be addressed. The notion in question is that of the role of human intention in archaeological explanation. Traditional scenarios forwarded to account for things like subsistence change often rely on the assumption that such changes must be the intentional result of rational choices by people to exploit some resources rather than others (e.g., Scarry 2002). A consequence of this position is that when archaeologists consider why a population underwent a change in subsistence, they presume that any perceived benefits that might accrue from a particular subsistence change provide the motivation, and hence the "reason," for the change. From this perspective, intention becomes a means of directing, or at least

explaining, change. Although most will concede that foragers did not "intend" to become farmers, if for no other reason than too much time was required (Rindos 1984; Winterhalder and Goland 1997), the question remains: Is there, as some (e.g., Boone and Smith 1998; Gremillion 1996a; Richerson et al. 1998; Rosenberg 1998b) have argued, a role for human intention in an evolutionary explanation of archaeological phenomena?

The Role of Intention

Certainly, people do make decisions and they usually hope for favorable outcomes. However, they cannot know at the time these decisions are made, no matter how thoughtfully conceived the solution, what the immediate, much less the ultimate, consequences will be. Consider, for example, the current crisis faced by populations of Bangladesh and West Bengal, India (Das et al. 1996; Medical Information Group 1998; Pearce 1998). Until the early 1970s, the people obtained their drinking water from surface and near-surface sources. The water was badly contaminated and many people, particularly children, were suffering from waterborne diseases like cholera. A solution was proposed by Western engineers and implemented over the past three decades by relief agencies – shallow tubewells, about 4.5 million of them in rural Bangladesh alone (Medical Information Group 1998), were drilled to provide a clean, safe water supply. Over the past 36 years, child (< 5 years of age) mortality has dropped by 13.5% to roughly 11% (United Nations Foundation 1999); this probably reflects the combined impact of cleaner water supplies, improved hygiene, and better access to medical aid.

The prevalence of tubewells has had unintended consequences, as well. In 1983, skin lesions characteristic of arsenic poisoning were first recognized in some individuals (United Nations Foundation 1999). Since then, tests have revealed that the water in many wells is contaminated with dangerously high levels of arsenic (the acceptable level of arsenic in water is defined by the World Health Organization as 0.05 mg/L; the levels documented in some tubewells range from

0.30 to 4.0 mg/L). Most of the population has not been assessed for arsenic-related health problems, but even so, thousands of people have been diagnosed with arsenic poisoning, known as arsenicosis. Upwards of 70 million people are at risk (Medical Information Group 1998) and it is expected that, as more people's exposures to high arsenic levels surpass the latency period of roughly ten years, one in ten adult deaths may soon be caused by arsenic poisoning (Pearce 1998). Although most available information remains anecdotal, by impacting adults of reproductive age disproportionately, arsenic poisoning would appear to have a greater fitness impact on these populations than waterborne disease did. Time (and more and better data) will tell, but despite best intentions and a huge investment in terms of both time and money, the solution appears to be worse than the initial problem.

The tubewell catastrophe illustrates well the dichotomy that exists between human intentions and behavioral consequences.[18] The notion that people intended to do the "right" thing does not change the selective consequences of their actions and the latter is what really matters in an evolutionary sense. Selection does not act on belief or intention; it acts on behaviors and the outcomes of those behaviors. If the outcome of a decision bears no relation to the underlying intent, then intention cannot be useful in any explanatory sense. Evolutionary explanations as scientific explanations are concerned with cause, not reason (Dunnell 1989, 1992). Indeed, this distinction is one of the principal contributions of using evolutionary theory to explain human phenomena.

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[18] The tubewell example is not an isolated one. A broad range of examples that illustrate the problem can be identified: (1) use of thalidomide to reduce symptoms of morning sickness among pregnant women, which produced severe birth defects and high early mortality rates among resulting "thalidomide babies;" 2) translocation of the cane toad (*Bufo marinus*) from South America to Queensland, Australia, to counter the cane beetle, which was damaging the sugar cane crop; although the toad has had no impact on cane beetles, it has subsequently outcompeted many native invertebrates and vertebrates; or 3) use of infant formulas to replace breastmilk in African countries, which resulted in xerophthalmia (blindness caused by vitamin A deficiency).

The perspective taken here (and this is consistent with evolutionary theory) is that what is important is that *some* behaviors, regardless of if or how they may be recognized or rationalized by the participants, increase the replicative fitness of their practitioners under *some* conditions while others do not. That extinctions have occurred supports the notion that people do not always make the "correct" choices (cf. Hitchcock 1982). In 20:20 hindsight, maize farming appears to have been the "right" decision (or at least one that worked) for many Eastern Woodland populations. This appearance arises only because alternative choices have been eliminated by selection. Maize farming was but one option among a larger but historically-limited number of options. Conditions were such that those populations who exercised alternative subsistence options apparently did not fare as well. Thus, when we consider why, for example, dietary change occurred in a particular situation, the important question is why that diet (of many possible diets) became fixed, rather than the imagined intentions of long-dead people who changed their diets.

Different Evolutionary Approaches to the Archaeological Record

Recently, both formal presentations and the published literature have promoted an increasingly rancorous "debate" in archaeology over the relative merits and shortcomings of the two main evolutionary approaches to the archaeological record: behavioral ecology (a subset of evolutionary ecology) and evolutionary archaeology (frequently mislabeled as "selectionist" archaeology). Critics on both sides and from without (e.g., Boone and Smith 1998; Broughton and O'Connell 1999; Hart 1999b; Lyman and O'Brien 1998; MacDonald 1999) have described several differences between the two approaches; the end result of such exchanges has been a series of caricatures of each program that does little to advance our understanding of either of them.

In brief, the behavioral ecological approach uses models derived through ecological, experimental and ethnographic research to account for

adaptations (Boone and Smith 1998; Broughton and O'Connell 1999). These models identify the costs and benefits (usually in the currency of energy) of different solutions to fitness-related problems, particularly those involving subsistence and settlement systems (e.g., Kelly 1995; Smith 1983; Smith and Winterhalder 1992a; Winterhalder and Smith 1981). Evolutionary archaeology, on the other hand, is more concerned with deriving historical accounts (or narratives) that explain the evolution of phenomena (Lyman and O'Brien 1998). Such narratives are constructed by tracking the historical trajectories of particular traits, the functional properties of which are examined using engineering analyses.

Both approaches are committed to developing testable accounts, using evolutionary processes, for patterning in the archaeological record and thus are potentially scientific. Rather than choosing to use one or the other, it seems that elements of both are necessary to develop a complete explanation for archaeological phenomena (cf. Lipo and Madsen 1998; Losos and Schluter 2000). Because my primary interest involves historical questions (why, when and where maize farming appeared), the overall structure of this research is within the framework of evolutionary archaeology, but I use elements of behavioral ecology when appropriate.

SUBSISTENCE AND DIET

SUBSISTENCE SYSTEMS

The term "subsistence system" refers to the set of activities by means of which energy and matter are acquired by a group of people (Cleland 1966; Earle 1980; Rice 1975). Because the mode of energy capture by a group of people directly impacts their success (by determining how much time and energy are available for reproductive and maintenance activities), documenting subsistence is a critical component to understanding why some individuals and/or populations fare better than others under particular conditions. Subsistence systems can be characterized

by their structure and content, which in turn are influenced by the richness, evenness, productivity and spatiotemporal structure of the local environment, as well as by resource extraction and energy/material storage technologies. The *structure* of a subsistence system refers to the numbers and kinds of resources exploited; *content* refers to the particular resources exploited.

Structure

Although they may vary along a continuum, organisms are often categorized as having either generalized (eurytopic) or specialized (stenotopic) adaptations (Emlen 1973; Levins 1968; MacArthur 1972; Pianka 1978). This distinction reflects the uneven empirical distribution of organisms along a resource or habitat continuum, with most found at one end or the other and very few in the middle (Hunn and Williams 1982; Kelley and Farrell 1998).

Among people, generalized (Earle 1980; diffuse *sensu* Cleland 1966, 1976; extensive *sensu* Dunnell 1967, 1972) subsistence systems utilize a set of diverse, unrelated resources obtained with unspecialized extraction technologies. Because such systems are characterized by substantial breadth involving an even structure of many resources from many habitats, they are not very efficient and often can maintain only low populations. On the other hand, generalized systems are flexible and tend to be quite stable in the face of temporary resource fluctuations (Dunnell 1972). They are exemplified by typical hunter-gatherer subsistence strategies.

Specialized (Earle 1980; focal *sensu* Cleland 1966, 1976; intensive *sensu* Dunnell 1967, 1972) subsistence systems use a few, related resources obtained with relatively specialized extraction technologies. They are marked by narrow breadth involving uneven resource use and are dominated by few resources from few habitats. Specialized systems are often based on coevolutionary relationships between humans and plants or animals (Rindos 1984). Relative to generalized subsistence systems, specialized systems are more efficient and can

support larger populations, but they are much less stable in the face of even minor perturbations (Dunnell 1972; Rindos 1984; Winterhalder and Goland 1997). Farming systems are specialized subsistence systems using plants.

Because the spatiotemporal structure of resources varies among regions and because resource exploitation varies along a continuum, the distinction between generalized and specialized adaptations is a relative one (cf. Futuyma and Moreno 1988). The differences between generalized and specialized subsistence systems at any place and time can be expected to be reflected in the diversity, especially the evenness, of resources exploited (Dunnell 1972; Rindos 1984; Whitlam 1981). Although some researchers have used taxonomic richness to differentiate subsistence systems (e.g., Broughton and Grayson 1993; Grayson and Delpech 1998), this approach may not always be successful; various mechanical (e.g., bone fragmentation and skeletal part representation) and analytic (e.g., how taxa are related ecologically and how resources are defined) factors may complicate the situation (Grayson and Cannon 1999; Grayson et al. 2001; Greenlee 2002). With respect to the latter, when taxa are aggregated into resource classes on the basis of the habitats they occupy and the acquisition technologies they require (cf. Allen 1992; Neusius 1986), subsistence systems may utilize many species yet still be considered relatively specialized. Resource evenness, the relative proportions in which resources are used, may be more useful for distinguishing generalized and specialized subsistence systems.

Content

The composition of a subsistence system reflects costs of resource location, acquisition and processing relative to other resources, mediated by the return (e.g., nutritional value) of the resource (Christenson 1986; Keegan and Butler 1987; Winterhalder and Smith 1981). While attempts to quantify harvesting returns and processing costs for individual resources (e.g., Asch and Asch 1978; Murray and Sheehan 1984; Reidhead 1981; Smith 1975, 1987) are laudable, they

are of limited explanatory value. There is no warrant to assume correspondence between modern/historic resource distributions (and collection or preparation techniques, for that matter) and prehistoric ones. Alternatively, relative return:cost ratios can be evaluated by documenting the frequencies with which resources appear in the archaeological record (i.e., frequently-occurring archaeological remains had high net return rates, while those that are less common had relatively lower net return rates [Broughton and Grayson 1993]) and the population trajectories with which they are associated.

DIET

It is necessary here to distinguish subsistence from diet because different kinds of data are necessary to address questions of subsistence and dietary change. Subsistence, the acquisition of resources both edible and inedible, is an attribute of the community; diet, the consumption of resources, is an attribute of individuals within the community. Aggregates such as floral and faunal remains inform about the subsistence system of a group of people; these kinds of assemblages represent pooled data reflecting the activities of a variable number of individuals over variable amounts of time and include materials acquired for reasons (e.g., competition suppression, raw materials) beyond simple dietary consumption. In contrast, diet, as an individual phenomenon, is best addressed through bone chemical analysis of individuals. Given this distinction between diet and subsistence, when archaeologists talk of "diet breadth" computed from faunal or floral assemblages (e.g., Broughton and Grayson 1993; Grayson and Delpech 1998), they really mean "subsistence breadth."

This distinction between subsistence and diet is important because, in simple societies at least, the individual is presumably the scale at which selection operates (Dunnell 1980b, 1995; Dunnell and Wenke 1979; Kelly 1995; Smith and Winterhalder 1992b). Thus, community-scale data are probably epiphenomenal (i.e., they are explained as the effects of processes operating at a lower scale). At

this higher scale, the causes of particular changes are difficult to pinpoint because they cannot be closely associated with the units of selection. For example, because assemblages must be treated as products of the entire community, we cannot link the demographic trajectory of individuals or lineages with the particular faunal or floral resources they exploited. This makes data about individual diets particularly important because they provide crucial information concerning the units of change (scale of individuals, lineages, communities, or populations).

Functional Aspects of Diet

That an organism's diet is functional, i.e., it measurably affects biological reproductive fitness, is clearly documented (e.g., Frisch 1975b, 1984; Gage and O'Connor 1994; Keys et al. 1950; McLester 1949; Pond 1986; Pond and Houpt 1978; Stein and Susser 1975; Stein et al. 1975). Indeed, maternal reproductive performance is one criterion used by some practitioners of animal husbandry to evaluate the adequacy of experimental diets (McLester 1949). Because these conditions have different ramifications for biological reproduction, it is useful to distinguish between undernutrition (starvation) and dietary deficiency/toxicity (lacks adequate amount or includes too much of a specific nutrient).[19]

Although controversial (e.g., Bongaarts 1980; Scott and Johnston 1982, 1985; Wood 1994b), the critical-fat hypothesis attempts to specify how undernutrition may affect reproduction. In modern human populations, a fat level of approximately 22% is necessary for women to maintain stable menstrual cycles; below that level, cycles become irregular, ceasing altogether under conditions of severe undernutrition (Frisch 1975a, 1975b). Thus, fecundity requires a minimum threshold level of maternal nutritional intake. Undernourished females tend to

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[19] This distinction is based in part on the classic scheme of Mayer (1976), who has identified four different states of malnutrition: (1) undernutrition, not enough food; (2) deficient diet, lacking in one or more essential nutrients; (3) secondary malnutrition, illness or some condition preventing digestion/absorption of nutrients; and (4) overnutrition, an excess of food or of particular nutrients.

reach menarche later, take longer to recover from pregnancy and lactation, and undergo menopause earlier than well-nourished women, decreasing the amount of time they are capable of reproduction (Frisch 1975b). In the event that a marginally-nourished woman becomes pregnant, her body will draw upon its own stores to provide for the growth and development of the fetus, attempting to shield it from nutritional stress. Assuming it survives, the resulting infant will have a low birth weight, a variable directly correlated with its probability of survival (Lechtig 1978; Stein et al. 1975; Vestal 1936), and an impaired immune system (Chandra and Newberne 1977); prenatal growth rate may also influence the timing of the adolescent growth spurt and reproductive maturity for that child (Frisch and Revelle 1971). The mother's nutritional status will influence her milk production and her ability to feed the infant. The child's nutritional status, in turn, will impact its immune system, its ability to battle infection, and its likelihood of survival (Chandra and Newberne 1977; Shell-Duncan 1993; Shell-Duncan and Wood 1997).

Animal research has shown that dietary deficiencies or toxicities in the maternal diet have variable effects on reproductive outcomes. Four potential scenarios involving specific nutritional deficiencies can be anticipated, here illustrated with examples from swine (Mahan and Vallet 1997; Pond and Houpt 1978): (1) no effect because sufficient amounts of the nutrient can be mobilized from maternal stores (e.g., Ca deficiency); (2) direct effect on the health of fetus, such as low birth weight and slow postnatal weight gain (e.g., severe protein deficiency); (3) pregnancy not successfully completed due to death of the fetus (e.g., vitamin E or folic acid deficiency); or (4) conception cannot occur (e.g., severe vitamin A or riboflavin deficiency). Nutritional toxicities influence reproductive success, as well. The outcome of nutritional stress of either form (deficiency or toxicity) seems to depend on the physiological status of the particular nutrient involved, the severity of deprivation/toxicity in the maternal diet, how much is stored in maternal tissues, its ease of mobilization, and the efficiency of transport across the placenta.

Although the effects of nutritional deprivation and deficiencies/toxicities can be observed and measured in laboratory settings, the job is far more challenging in uncontrolled situations, and nearly impossible for archaeological skeletal populations. First, the complexities of biological metabolism and post-depositional alteration make it unlikely that nutritional status can be directly evaluated through chemical means; hence, skeletal morphology is the most likely method for determining nutritional adequacy. Second, the effects of nutritional deficiencies are not always linear, i.e., a physiological threshold must be undercut in order to produce observable skeletal manifestations. Third, interaction effects with other nutrients may produce secondary deficiencies which confound diagnosis of the organism's physiological response. Finally, with few exceptions, (e.g., rickets [Vitamin D deficiency] and scurvy [Vitamin C deficiency]), observable skeletal and dental pathologies cannot be attributed directly to specific nutritional conditions. Indeed, disease often has a synergistic effect with poor nutrition, making it difficult, if not impossible, to separate their roles in producing skeletal pathologies – hence, pathologies such as Harris lines, porotic hyperostosis, and enamel hypoplasias are best considered to be non-specific "stress" indicators.

Assessing Fitness

Since functional traits will spread at a rate proportional to the degree of advantage they confer upon individuals with those traits (Dunnell 1978), a dietary phenotype that provides significant benefit relative to another will rapidly replace it. Both cultural and genetic transmission are involved in the spread of particular dietary phenotypes. This makes the mathematics of the situation complex, as there is no one-to-one correspondence between the spread of traits like diet and the genetic fitness of "individuals." With cultural transmission, organisms may experience a succession of dietary phenotypes over their lifetimes. The organism and individual become decoupled. Although cultural transmission may play a relatively greater role in dietary change because of the speed with which such

transmissions can occur, as demonstrated above the impact that diet has on the survival and genetic reproductive potential of individuals cannot be ignored.

Analysis of DNA extracted from hard tissues, teeth in particular, may allow archaeologists to establish clearly the (genetic) reproductive success of lineages. In the absence of DNA or skeletal nonmetric/metric traits to demonstrate the degree of relatedness among individuals, determining (genetic) reproductive fitness in archaeological skeletal populations is a difficult proposition. Relative biocultural fitness associated with different subsistence and/or dietary conditions is reflected in the demographic structure and trajectories of the populations that employ them. Addressing the demographic structure of prehistoric groups requires inferences about trends in fertility and mortality and evidence for generalized physiological stress ("health") on the basis of cross-sectional data from potentially-biased mortuary populations. This is not without problems.

In terms of fertility and mortality, it is unknown to what degree a skeletal collection is a sample of the living population. Recovered skeletal collections are usually only a sample of actual burial populations, and hence are subject to several sources of error, including n-transforms (i.e., are the chemical and mechanical properties of the deposit such that infants and children are likely to be underrepresented due to post-depositional factors?), sampling error (i.e., is the skeletal assemblage recovered an unbiased sample of the burial population?) and analytic error (i.e., is there systematic error in age or sex estimation?). In turn, burial populations cannot be assumed to be representative samples of living populations and, thus, are also subject to bias (i.e., does the burial assemblage include the entire population, or were some segments of the population treated differently at death [not all bodies buried or, if buried, not in the same way and/or place] and are not represented in the sample?).

Another rather knotty problem, known as the "osteological paradox," is associated with the interpretation of skeletal pathologies (Wood et al. 1992).

Traditional analyses of skeletal populations have viewed high frequencies of skeletal pathologies in a population as an indication of the relatively poor health of that population (Cohen 1994; Cohen and Armelagos 1984). This position assumes that the physiological stress responsible for the visible skeletal pathologies was responsible for the individual's death. Individuals whose skeletons lack pathologies are presumed to have been healthy and disease-free. More recently, however, it has been suggested that high frequencies of skeletal pathologies in a population might be better regarded as an indication of the relatively good health of that population (Wood and Milner 1994; Wood et al. 1992). This latter position argues that individuals who lived long enough to record skeletal pathologies as a response to physiological stress were healthy enough to have survived that stress; individuals who were free of pathologies succumbed to stress before their skeletons could respond.[20] No matter how one looks at it, it is exceedingly difficult to conclude anything about the "health" of living populations based on an analysis of a necessarily biased sample, the dead.

There are problems with the notion "health." As it is commonly construed, the term bears no direct relation to (genetic) reproductive fitness. Wood (1998) has suggested that "health" be replaced by the concept of "well-being." He defines well-being as "any aspect of individual health or physical condition that is either positively associated with the probability of childbirth or negatively associated with the risk of death" (1998:133) and he notes that it is closely linked to the available food supply. Definitionally, well-being has fitness implications even if it is not yet clear exactly how it might be operationalized with respect to the archaeological record.

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[20] Comparing the mean age-at-death between populations with high and low rates of skeletal pathology might be one way to get around the paradox. The argument, however, centers on comparisons between populations with different subsistence (farmers vs. hunter-gatherers) and settlement (nucleated vs. dispersed, sedentary vs. mobile) systems; given these differences, it is unlikely that the age structure and frequency of non-illness deaths would be comparable.

Stylistic Aspects of Diet

It seems clear that a better maternal nutritional status is associated with a greater likelihood for a successful birth outcome (Worthington-Roberts and Williams 1989). However, the fact that population growth in contemporary society continues at a rapid pace even among very poorly nourished populations suggests that, once basic nutritional requirements are met, survival and reproduction may be fairly insensitive to the particulars of nutritional status.[21] Some components of the diet may not measurably affect the reproductive success of organisms and thus, there may be a stylistic (adaptively neutral) component to diet.

Different kinds of leaf lettuce, varieties of apples, brands of cola, or sorts of snack foods (that cost roughly the same) might be contemporary examples of stylistic components of the diet. As long as variants have approximately the same cost and nutritional value; the temporal and spatial distributions of such alternative, functionally equivalent, food resources as components of the diet are probably governed by stochastic processes. I have suggested elsewhere that such components are likely to be minor contributors to the overall diet and that our current level of analytic resolution is probably insufficient to identify the stylistic components of prehistoric diets (Greenlee 2001a).

Stylistic and functional attributes have different distributions in time and space. Because stylistic attributes do not interact with the environment, they will not map onto environmental features. The spatial distribution of eight-row maize cobs (Figure 18) or elk and bear remains (Figure 22), for example, do vary with the structure of the environment; those attributes appear to be functional and we have, at least, an intuitive appreciation of why they might be so. The distribution of bean shape (length:width ratios) shown in Figure 19, however, does

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[21] Modern health care practices (e.g., immunization, vitamin and mineral supplementation) may well play a strong role in mitigating the impact of otherwise inadequate diets, particularly by altering nutrient thresholds.

not appear to correspond in any obvious way with environmental features. Thus, bean shape may be a selectively neutral attribute and this pattern of bean shape may reflect patterns of cultural interaction, much as ceramic styles may. Before that can be shown, however, other data are required: finer chronological resolution to establish how bean shape may have varied over time, more detailed information about how bean shape responds to different carbonization processes and how bean growth may be affected by environmental conditions, and measurements from more locales to better establish the geographic distribution of bean shape. This is not an intractable problem – it is just a matter of collecting the necessary information.

IMPLICATIONS

The appearance of maize farming in eastern North America represents a major subsistence reorientation that has occupied archaeologists working there for a very long time. As Chapter Two shows, when, how and why this change occurred continues to elude resolution. Although many scenarios have been proposed to account for various aspects of the subsistence record, there is no consensus as to what the best explanations are. Evolutionary theory provides a consistent and scientific framework in which these questions can be answered. To explain why different subsistence systems appeared where and when they did, both historical and functional information are required.

PREVIOUS EXPLANATIONS RECONSIDERED

Chapter Two reviews some of the causes previously advanced to account for subsistence variation in the Ohio Valley and elsewhere in the Eastern Woodlands. Below, those scenarios are evaluated from an evolutionary perspective and empirical implications are derived for each that would permit them to be tested directly using the archaeological record. Rather than providing a list of specific hypotheses to be tested, this section points out what kinds of subsistence variation might result from changes in those four parameters (climate, demography, available

resources and technology, and social factors) and how that variation might be detectable in the archaeological record.

CLIMATE

The basic premise of this hypothesis is that climatic changes that alter the productivity, distribution, and/or predictability of various resources will have implications for the populations that exploit those resources (e.g., Anderson et al. 1995; Stahle et al. 1998; Wuethrich 2000). Before going any further, it is important to note that suggesting a relationship between climate and culture does not imply environmental determinism. There is a difference, not always appreciated by archaeologists, between assuming that climate *causes* culture change by forcing populations to adapt to new conditions and assuming that climate changes the selective conditions in which populations operate, to the benefit of some individuals and to the detriment of others. The former is clearly an environmental determinist position; the latter is an evolutionary position and it is the one taken here.

The first step in addressing the role of climatic change on subsistence requires that the climatic history for the region be arrayed against the subsistence record. The climatic history of the Ohio Valley is not well known. Using a suite of climate proxy data (pollen, beach ridges, tree rings, borehole temperature profiles) from surrounding areas and macrophysical modeling, I develop a new model of climatic change for the region.

If any correlations obtain between the climatic and archaeological records, it is necessary to establish how the documented climatic change would have impacted the resource base (cf. Basgall 1999) and assess whether the archaeological record is consistent with that sort of impact. In positing what kinds of impacts changing climate may have had on prehistoric subsistence systems, it is important to consider how climatic variables are distributed spatially. Subsistence systems

located in areas that are closer to climatic limits for the resources which they exploit should show the greatest impact when climate changes. Alterations to the resource base should be reflected in the content of subsistence systems (i.e., changed frequencies or presence/absence of climatically-sensitive taxa).

DEMOGRAPHY

Demographic scenarios for the appearance of farming systems have traditionally relied on the assumption that increases in population size or density "strained" the local resource base and spurred subsistence reorganization. Winterhalder and Goland (1997) correctly point out that such scenarios are functionalist in that the presumed benefits of farming account for its origin. In addition, I would argue that the structure of many such scenarios, by assuming that people responded rationally and (ultimately) correctly to the problem of resource depletion due to high local population density (e.g., Rose et al. 1991; Welch 1990), is not evolutionary – natural selection does not play any role. In most general terms, the generation of variation is linked tautologically to the conditions of selection. There is, however, a kernel of logic in this kind of "explanation" when examined from an evolutionary point of view under some limited conditions, namely when a change in selective conditions occurs as a result of increased population that favored individuals consuming particular diets, i.e., density-dependent selection.

There is potentially an empirical problem with demographic scenarios, as well. Rindos (1984) has observed that increases in population are more likely to be a *product* of specialized subsistence than a cause of it. It would seem, then, that the first step in evaluating the demographic hypothesis for maize farming would be to compare the timing for population increase and subsistence change.

Although the impact of "population pressure" on subsistence is usually discussed in terms of population size or density, it is probably better

considered as an effect of the ratio of consumers to resources (cf. Wood 1998). It is necessary to demonstrate that the number of local consumers increased, either through spatial reorganization (i.e., settlement aggregation or sedentarization) and/or through biology (i.e., increased fertility and/or decreased mortality). Number of settlements, settlement size and roofed habitation area can be used as an ordinal scale measure of the number of local consumers (Ramenofsky 1987 and references therein); changes in fertility/mortality can be determined through cautious use of the age structures of burial populations (Milner et al. 1989). The temporal relationship between demographic and subsistence change can then be examined (cf. Cannon 2000). If the appearance of maize farming preceded demographic change, then demography can be rejected as a cause for that subsistence change; if demographic change preceded maize farming, the demographic hypothesis remains a viable explanation for the origin of farming systems in the region through density-dependent selection.

Demography has played a role with respect to other sorts of subsistence change, as well. Thus, even if maize farming was not a consequence of demographic change, other parts of the subsistence record may have been and these other potential implications of demographic change on subsistence need to be addressed (cf. Cannon 2000). Three different kinds of evidence may reflect the impact of an increasing consumer:resource ratio.

Resource Depletion

Ecologists argue that decreased resource availability due to overexploitation may be resolved by expanding the number of different resources used. Previously-ignored or rarely-used resources that provide a smaller net return may be added to the subsistence system as those with a larger return become scarcer. Thus, in the absence of other selective forces, resource richness and evenness may increase and the proportion of, say, large:small game (e.g., deer vs. rabbit) will decrease (Broughton 1994b; Kaplan and Hill 1992). As noted by Welch

(1990), animal size within taxa may also decrease and evidence for human undernutrition may be frequent. Faunal evidence for increasing frequencies of logistical forays outside the local catchment may also signal resource depletion (Broughton 1995). Again, these parameters are complex and all may be caused by factors other than human predation, necessitating further analyses to rule out other causes (cf. Broughton 1994b, 1995; Grayson and Cannon 1999).

Competition

Competition has been defined as "a negative effect of one species upon the population size of another arising from their joint exploitation of environmental resources" (Grant 1986:183); by substituting *population* for *species*, this definition can be applied to both intra- and inter-specific cases. Competition for limited resources increases the costs of acquiring those resources (Anholt and Werner 1998; Boone 1992). Larger group sizes and/or decreased catchment areas (associated with more concentrated resources) may somewhat reduce those costs. Increased commitment to maize farming in fields near the settlement may raise local productivity sufficiently to support a larger group than supportable by wild resources or the EAC plants. Evidence for intraspecific competition among humans may be recorded in several ways: settlement locations may be biased toward more "strategic" situations, with the construction of defensive structures (e.g., palisades), and/or increased numbers of violent deaths. Interspecific competition for resources with other, nonhuman predators might be evidenced by greater abundances of potential competitors' remains, increased proportion of local acquisition of competitive fauna, and/or lack of evidence that those remains were processed either for food or for nonfood uses.

Cooperation

Although competition seems more typical of simple societies (e.g., Chagnon 1979), cooperation within groups (Boone 1992; Hawkes 1992; Kelly 1995) might have served to increase task efficiency (depending upon the task and the

demographic structure of the group). Furthermore, cooperation might increase the day-to-day consistency of food intake through resource-sharing and the likelihood of successful defense against hostile neighbors. Evidence for cooperation is nearly impossible to identify in the archaeological record using standard techniques, however. Communal animal drives, which would be reflected in the population structure of the prey's remains (Cleland and Kearney 1967b; Klein 1982; Waselkov 1978), and construction of community structures (e.g., palisades, mounds) are perhaps the best examples of cooperative tasks that might leave an easily-detected trace.

Cooperation between groups, if it involves the exchange of items, may also be variably evidenced in the archaeological record. The presence of exotic goods (as either raw materials or manufactured items) may be reasonably argued to be the products of exchange; marine shell and cannel coal in Late Prehistoric-aged deposits across the study region, in particular, are exotic products that had to have been moved over long distances. The distribution of stylistic attributes may be useful in demonstrating local patterns of interaction and exchange among groups (Lipo et al. 1997), patterns that *might* reflect exchange with regard to subsistence resources, as well. The exchange of food items, however, might be a difficult case to make (Earle 1994; Minnis 1985). First, many foods are not preserved and second, no potential food resources in the region are from areas so restricted in geography that one could rule out travel to obtain them. Even if one could demonstrate (e.g., using trace element compositions or DNA) that resources were acquired from extra-local sources, they were not necessarily obtained through exchange, but they could have been. Labor exchange would leave no archaeologically-visible trace, except perhaps for slight scheduling changes among the involved parties. Cooperative resource exchange could have occurred between different farming groups occupying different microenvironments or between farming and hunter/gatherer groups (e.g., Gregg 1988; Hart 1995; Spielmann 1986).

The presence of "foreigners" in a community could reflect cooperation or competition. Although archaeologists typically lean toward the former, often assuming some manner of marital exchange, there is strong ethnohistoric evidence that, among some Northeast tribes at least, one reason for warfare was to capture prisoners, some to torture and some to replace deceased kin (Brandão 1997). Generally recognized by differing burial treatment and/or skeletal traits (e.g., patterns of cranial deformation), the foreigners may introduce some variation into dietary studies simply because they lived some of their lives somewhere else eating a different diet. Stable isotope and/or trace element analyses (particularly of tooth enamel) or DNA analyses might allow foreigners to be identified more reliably (Carlson 1996; Ericson 1985; Price et al. 1994, 2000; White et al. 1998).

Available Resources and Technology

Non-climatic or -demographic changes to the resource base may also play a role in subsistence change. The introduction of new varieties of plants from elsewhere, *in situ* changes in the characteristics of established plants, and the adoption of different technologies are the key factors in this suite of scenarios. The key to evaluating these factors as explanations of subsistence change will lie in establishing how they affected the success of the populations employing them.

Demonstrating the introduction of new plants into the region (e.g., beans) is a relatively straightforward proposition, achieved by collecting archaeobotanical data from many large, well-dated assemblages. It will be more difficult to establish the appearance of new varieties of existing plants (e.g., new varieties of maize); such varieties may only be identifiable with detailed archaeobotanical measurements or, if the changes are not reflected in the morphology of preserved plant parts, by consideration of the depositional contexts in which the remains are found. Finally, technological change may be evidenced in the tools used, the microenvironments and/or suite of resources exploited, the seasonal

schedule of resource exploitation, or in particular characteristics of the resources exploited (cf. Broughton 1994b, 1995; Grayson and Cannon 1999).

SOCIAL CONTEXT

With the exception of evidence for population movement and diffusion of attributes between groups, the testability of scenarios about subsistence change that fall into the category of social context is problematic. In many cases, these social scenarios have been proposed when economic variables do not appear to account for subsistence variation. Social scenarios often rely on variables that are theoretically undefined and that are without empirical relevance in the archaeological record, which renders them ultimately untestable; such scenarios also tend to be vague, particularly with respect to mechanisms of change, presumably because it is intuitively obvious how social factors could have the speculated impacts (cf. Dunnell and Greenlee 1999).

Outside Influence and Population Intrusion

While arguments for a Mississippian intrusion into the middle and upper Ohio Valley have been dispatched previously, there is evidence for the diffusion of ideas and plants among Eastern Woodland populations. The expansion of specialized maize farmers into new areas, perhaps at the expense of local populations with more generalized subsistence systems, also seems to have occurred. The former situation, diffusion, will be recognized by the addition of extralocal attributes to an *in situ* material culture. With population replacement, there will be no continuity with the local occupants; similarity will be limited to analogous resemblance. There may be indications of contemporaneous occupations in an area by communities with distinctly different subsistence systems.

Social and/or Political Reorganization

In simple societies, like those of the prehistoric Ohio Valley, probably the best archaeological evidence for inter- and intra-community differences in social

and/or political organization would involve variation in settlement structure and burial treatment. A change in either of these variables concurrent with the appearance of maize farming would be an important observation. A scientific explanation, however, requires that we go beyond correlation to establish causation. We need to show how the posited changes in the social environment would change selective conditions with respect to subsistence and diet, benefiting some individuals and not others. Similarly, the assertion that different social groups consumed different diets, even if empirically true, does not explain how or why such a pattern might appear and persist. The necessary linkages are decidedly lacking.

Consider the notion of "status." Archaeologically, evidence for "status" differences is generally restricted to burial treatment (personal grave goods or location and form of interment) or other markers (e.g., dietary differences). Scenarios that invoke social status to account for variation in the archaeological record treat the link between status and burial treatment and/or diet as "obvious" and not in need of justification. As if that were not problem enough, the presumed markers of status vary across different circumstances (e.g., high maize consumption is sometimes a marker of high social status and sometimes a marker of low social status; similarly, grave goods are often considered to be markers of social status when found with adults, but are apparently treated as markers of affection when found with infants and children). Finally, it is unknown whether people got to eat corn because they had high status (or didn't get to eat corn because they had low status) or whether they had high status because they ate corn (or had low status because they didn't eat corn). Again, the common-sense origin of the status interpretive algorithm is clear. Such arguments make sense only because we, as English-speaking Americans, share common cultural values and meanings. Clearly, attributing observed differences to "status" adds nothing; it is simply relabeling, not explaining.

Cultural Meaning and Rituals

When artifacts are restricted in context, association, or condition, that patterning may inform about the way they were used, treated or discarded (when taphonomy, sampling and recovery can be eliminated as sources of patterning). Accordingly, archaeologists often interpret artifacts that are patterned in such a way that does not make intuitive functional "sense" as "ritual" behaviors. Some go further to speculate what these materials may have "meant" to prehistoric peoples in a symbolic sense. Clearly, our speculations cannot provide the basis for scientific explanation because they are untestable. Further, when dealing with subsistence remains, what they "meant" to prehistoric people does not obviate the need for food or the effects of nutrition on the human body.

Concepts like "ritual" or "cultural meaning" are not evolutionary constructs and they have no explanatory power within an evolutionary framework, but that does not mean the kinds of patterns chalked up to "ritual" are inexplicable. Even when plant and animal remains are associated with cultural elaborations like burial mounds, they are likely still functional (i.e., they impacted the replicative fitness of individuals), either as consumed food and other raw materials or as "waste." With respect to the former, subsistence remains associated with mortuary phenomena may reflect intra- or inter-community food exchange (Seeman 1979). With respect to the latter, Dunnell (1989) and others (Kornbacher and Madsen 1999; Madsen 2001) have begun to sketch the means by which waste (energy expenditure that does not increase the immediate survival or reproduction rate of organisms) may be explained. We do not need vague ethnocentric notions like "ritual" or "social meaning" to account for "unusual" distributions of subsistence remains.

Because scenarios that fall under the rubric of social/political reorganization and cultural meaning/rituals are largely speculative, they cannot be viewed as testable hypotheses. In some cases, selected aspects of the scenarios can

be evaluated and in others, the most that can be accomplished is to examine more thoroughly the empirical data that serve as the source for such interpretations.

Empirical Implications and Research Structure

The most critical step in explaining why maize farming appeared when and where it did and in what forms it did lies in establishing how subsistence systems varied through time and across space. Once those data are generated, they can be arrayed against other parameters that will allow us to evaluate hypotheses about that change. Because maize was present in the area long before it became a dietary staple and because there are many unknown biases with respect to the preservation and recovery of maize specimens, the presence and/or relative frequency of maize remains in archaeobotanical assemblages are not very sensitive indicators of the relative importance of maize in prehistoric subsistence systems. Stable carbon isotope ratios, which reflect an individual's level of maize consumption, provide a better reflection of the importance of maize in prehistoric subsistence systems.

The available stable carbon isotope data are not adequate for the level of detail required by this research, thus generating more isotopic data is the single most important need. For that reason, this research emphasizes the generation of stable carbon isotope data from 251 individuals from Ohio Valley skeletal populations. The information acquired about the timing and degree of commitment to maize consumption in subsistence systems there can then be arrayed against other parameters to test hypotheses about the appearance and spread of maize farming.

For each of four groups of scenarios, a set of empirical implications has been derived that allow them to be tested, some more straightforwardly than

others.[22] There is some overlap among the hypotheses in terms of their implications and, because history is unique and unpredictable, not all empirical implications of any hypothesis may be met. Thus, when evaluating the hypotheses, it is important to look at a suite of variables and not rely on a single piece of evidence. Note, too, that some of the hypotheses have been suggested previously (as *post hoc* interpretations) on the basis of empirical evidence; thus, additional data must be included in these evaluations to avoid circularity. Finally, some hypotheses have a speculative element, primarily because little is actually known about attributes of maize and prehistoric farming systems. Additional research will be required to further evaluate those propositions.

CONCLUDING REMARKS

Scientific evolution provides a theoretical perspective for explaining subsistence change represented by the appearance and spread of maize-based subsistence systems in the Eastern Woodlands. Each of the several scenarios that were previously proposed to account for various aspects of the archaeological record of subsistence change was reconsidered here from an evolutionary perspective and to the degree possible, test implications were derived. Importantly, the different variables could produce subsistence systems that differ in structure and content, as well as in other ways (e.g., dietary composition, environmental location, settlement structure). Because adequate data on the role of maize in prehistoric diets are lacking and because they are so critical to this research, I concentrate my efforts on establishing a record of isotopic dietary variation through the Late Woodland and Late Prehistoric periods in the middle and upper Ohio River valley. Chapter Four

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[22] Some hypotheses require data generation and analysis beyond the scope of this research and thus, not all of them can be considered with equal thoroughness.

builds the case for isotopic analysis of human skeletal remains as a reflection of diet by describing in detail how it works and its implications for this research.

CHAPTER FOUR: BONE CHEMISTRY AND ISOTOPIC DIET

This chapter documents and evaluates evidence for dietary variation across the study area during the time period of interest. Although many kinds of archaeological data, ranging from grinding stones to faunal and botanical remains to skeletal pathologies like cribra orbitalia, are often treated as if they inform on prehistoric diet, most have no direct link to food consumption by individuals. Indeed, only three kinds of data (dental features, specifically tooth wear and carious lesions; coprolites; and tissue chemistry) have direct relationships with diet. The analysis of dental features only allows general statements about certain characteristics (e.g., abrasiveness, stickiness) of chewed items (Powell 1985). In the case of coprolites, only undigested components of the diet from the previous 24 hours or so are present; thus, even with DNA analysis to identify specifically the composition of specimens, they represent some unknown proportion of the total annual diet for a small number of unidentified individuals (Fry 1985; Stokstad 2000; Watson 1974b). Finally, tissue chemistry may provide less specific information about what particular items were consumed than coprolites, but it has the advantage of being averaged over longer periods of time and it is tied to particular individuals. It is this last data source, tissue chemistry, that is of interest here.

DIET AND TISSUE CHEMISTRY

Several different chemical components of an animal's tissues have been identified as reflecting the dietary intake of that component. The stable isotopes of carbon and nitrogen and the trace elements strontium and barium are perhaps the best known of the suite of indicators used by archaeologists in their attempts to address questions about prehistoric diet. Determining which isotope(s)

or trace element(s) to measure in a given archaeological application must consider the different strengths and weaknesses of each. Many reviews that evaluate the relative benefits and liabilities of each approach in different archaeological contexts are published (e.g., Ambrose 1993; Ezzo 1994; Katzenberg 1992; Katzenberg and Harrison 1997; Keegan 1989; Pate 1994; Price 1989; Sandford 1992; Schoeninger and Moore 1992; Schwarcz and Schoeninger 1991; Sillen et al. 1989). Of those reviews that consider questions about variation in the dietary consumption of maize in eastern North America, all agree such questions are best addressed through the analysis of stable carbon isotopes (although in some places [e.g., coastal areas] additional data are needed). Stable carbon isotopes[23] are useful because their distributions in terrestrial plants happen to be structured in a useful way.

STABLE CARBON ISOTOPE RATIOS AND DIETARY ANALYSIS

In plants, stable carbon isotope ratios reflect the biochemical pathways of atmospheric carbon dioxide (CO_2) during photosynthesis (Bender 1968; Smith and Epstein 1971). The chemical reactions that occur with CO_2 uptake and reduction preferentially incorporate or exclude ^{13}C relative to ^{12}C; this is known as fractionation. In eastern North America, where the native vegetation is strongly skewed toward plants which utilize the C_3 (Calvin-Benson) photosynthetic pathway, the $\delta^{13}C$ values of most plants range from -35 to -20 ‰ (Deines 1980; O'Leary 1981, 1988; Smith and Epstein 1971). Only a few plants in the region (e.g., *Amaranthus*,

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[23] Stable carbon isotope ratios are expressed as delta (δ) values in parts per thousand (‰) relative to the isotopic composition of a standard and are calculated as shown below. The standard, known as PDB, is a marine carbonate (belemnite) from the Peedee Formation of South Carolina; by convention, PDB has a $\delta^{13}C$ value of 0 ‰ (Craig 1957). Most naturally-occurring materials have concentrations of ^{13}C lower than PDB, hence their $\delta^{13}C$ values are negative.

$$\delta^{13}C = \frac{\frac{^{13}C}{^{12}C}\text{ sample} - \frac{^{13}C}{^{12}C}\text{ standard}}{\frac{^{13}C}{^{12}C}\text{ standard}} \times 1000$$

Atriplex, and some grasses) are known to use to the C_4 (Hatch-Slack) photosynthetic mode, which results in $\delta^{13}C$ values ranging from -16 to -7 ‰ (Deines 1980; O'Leary 1981, 1988; Smith and Epstein 1971). Maize, an introduced plant of tropical origin, uses the C_4 photosynthetic pathway. Thus, isotopically-speaking, maize is a rare resource in the area.

The tissues of animal consumers reflect the isotopic composition of their diets (and how closely will be addressed below), so significant consumption of an isotopically-distinct resource will be recorded in the tissues of the consumer. Certainly, it is possible that maize could be confused isotopically with the few other C_4 resources in the area. However, the other floral resources suggested from archaeobotanical evidence to have been consumed in significant amounts (e.g., goosefoot, maygrass, erect knotweed, beans, gourd/squash, sunflower and mast) have been analyzed isotopically and they have been identified as C_3 plants (Buikstra et al. 1988; Smith and Epstein 1971). The only nonmaize C_4 dietary resource identified thus far is amaranth, which was at best a minor contributor to prehistoric diet (Schwarcz et al. 1985); during the Middle and early Late Woodland periods, when amaranth remains are perhaps most ubiquitous, that C_4 resource had no identifiable impact on the isotopic composition of human populations in the region (Figure 8). In eastern North America, then, stable carbon isotopes in body tissues reflect the degree to which the diet of an individual is focused on maize. The diet-tissue relationship is sufficiently complex, however, to preclude the use of simple algorithms to reconstruct dietary composition quantitatively.

Experimental research into the relationship between the isotopic composition of an animal's diet and its tissues has shown that the exact nature of that relationship varies with the particular body tissue. Figure 27, for example, illustrates differences in the stable carbon isotope composition of several tissues in gerbils, mice, kudu and sheep relative to diet. It has been noted (DeNiro and Epstein 1978; Fry et al. 1978; Schroeder and Ben-Ghedalia 1986; Tieszen et al.

1983; Tieszen and Fagre 1993b) that the variation among these tissues may reflect (1) different biochemical sources for, and/or metabolic pathways of, tissue synthesis, (2) different biochemical compositions of the body tissues, and/or (3) different turnover rates (relevant only when the organism is in disequilibrium after experiencing a dietary change). The point here is that, to ensure comparability among different individuals, the same body tissues must be analyzed for each.

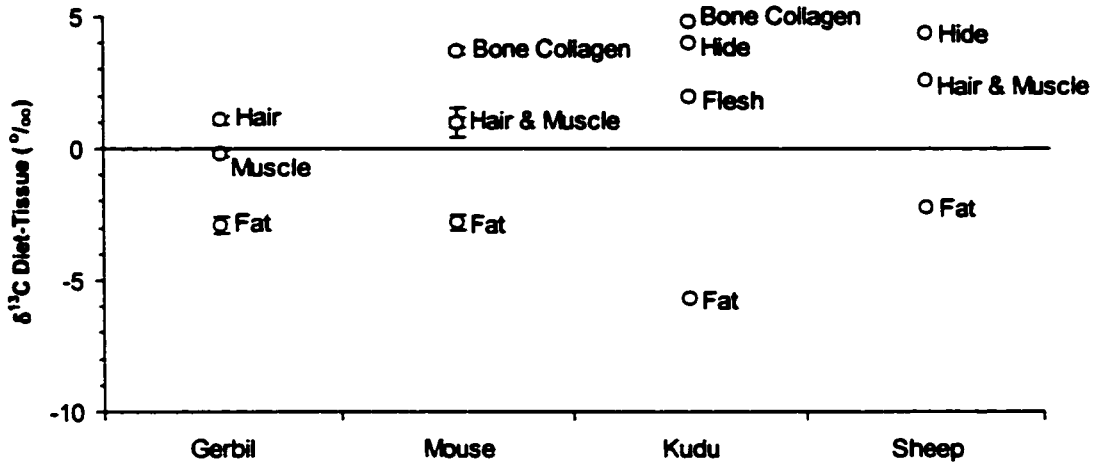


Figure 27. **Stable carbon isotopic composition of some body tissues relative to diet.** Here, dietary $\delta^{13}C$ (estimated for the free-ranging kudu and sheep) is standardized to 0 ‰; enriched tissues have positive values and depleted tissues have negative ones. Error bars indicate single standard errors for tissues from multiple samples, available for gerbils and mice only. Data on gerbils (n = 5) are from Tieszen et al. (1983), on mice (n = 4) are from Tieszen and Fagre (1993b), on kudu (n = 1) are from Vogel (1978), and on sheep (n = 1) are from Schroeder and Ben-Ghedalia (1986).

Teeth and skeletal remains are the only body tissues routinely preserved in archaeological deposits of eastern North America and, in modern animals, they both reflect dietary intake. Although using tooth enamel in dietary studies appears to have some advantages over bone (e.g., greater stability with respect to postdepositional alterations [Koch et al. 1994; Lee-Thorp and van der Merwe 1991; Wang and Cerling 1994]), bone has historically been the most

frequently and most easily obtained material for chemical analysis. Human bone is the material analyzed here.

Although its precise composition varies somewhat depending upon the type of bone and other circumstances (e.g., age and diet), whole bone is roughly 69% inorganic calcium phosphate, 22% organic matter, and 9% water (Triffitt 1980). The organic phase is dominated by collagen (88% by weight) and glycoproteins (8 – 9%), with minor contributions from approximately 200 other noncollagenous proteins, lipids, mucopolysaccharides, and other materials (Delmas et al. 1984; Stafford et al. 1991). Collagen is a large protein, composed of 18 amino acids which are organized in long chains, three of which are wound together in a triple helix to produce one molecule with a molecular weight of 285 – 300 kiloDaltons, or kD (Woodhead-Galloway 1980). Structurally, collagen provides the organic fibrous matrix in which crystals of nonstoichometric hydroxyapatite [$Ca_5(PO_4)_3OH$], the major calcium-phosphate phase found in bone, are deposited. Carbonate ions adsorb onto the mineral surface and occur as substitutions in the phosphate position in the calcium-phosphate lattice (Posner 1987). Because there are other calcium-phosphate phases in addition to hydroxyapatite that may contain carbonate ions, the term bioapatite is often used to refer generally to the mineral fraction of bone. The important point here is that both the organic and mineral fractions of bone contain carbon and both sources of carbon have been utilized in stable isotope studies.

Models to Account for Isotopic Fractionation in Bone

When isotope ratios are measured for both fractions of bone in the same individual, very different numbers result. The mineral fraction, bioapatite, consistently records significantly greater ^{13}C enrichment than does collagen in the organic fraction. There are two opposing models (Schwarcz 1991) that describe how the stable carbon isotope ratios of collagen and bioapatite are related to diet: the linear-mixing and the isotopic-routing models. The linear-mixing model posits that the consumer's tissues are formed from a common pool of carbon derived from the

entire isotopic diet (e.g., Schoeninger 1989b; van der Merwe 1982; van Klinken 1991) and that the differences between bioapatite and collagen $\delta^{13}C$ values result from the different processes involved in synthesizing those different tissues and their biochemical constituents. In contrast, the isotopic-routing model states that dietary components are preferentially routed in the synthesis of particular tissues (Chisholm et al. 1982, 1983b; Krueger and Sullivan 1984) and that the differences between bioapatite and collagen $\delta^{13}C$ values result primarily from isotopic differences in the biochemical sources of those tissues and secondarily from processes of tissue synthesis.

These two models have different implications with regard to the isotopic relationships among bone collagen, bioapatite and the diet consumed. If the linear-mixing model is correct, then the isotopic compositions of collagen and bioapatite should have a constant relationship with the isotopic composition of the bulk diet, and there should be a constant relationship between the two phases. With the isotopic-routing model, bioapatite $\delta^{13}C$ values should closely follow the isotopic composition of the bulk diet (because bone carbonate will be deposited in equilibrium with blood bicarbonate, itself influenced primarily by the metabolism of the "energy" component of the diet). Collagen $\delta^{13}C$ values, on the other hand, should be most closely tied to the isotopic composition of the protein component of the diet. Because essential amino acids present in collagen and other tissues must be obtained dietarily (and cannot be synthesized from other biochemicals), a minimal amount of routing must take place; the question becomes, can the linear-mixing model account for the rest of the isotopic signal? With the accumulation of empirical evidence, it has become clear that there is variation in the isotopic composition of bone for which the linear-mixing model cannot account.

One line of evidence seemingly against the linear-mixing model is that the isotopic relationship between diet and bone collagen appears to differ among taxa. Figure 28 plots the isotopic difference between diet and bone collagen

for a range of modern terrestrial mammals. Large free-ranging herbivores tend to show greater enrichment than the small animals typically involved in controlled-feeding studies. This was initially considered by most researchers to be a result of different metabolic rates among animals (e.g., van der Merwe 1982), interlaboratory differences in sample preparation and measurement calibration (e.g., Chisholm et al. 1983b), and/or error involved in estimating the isotopic diet consumed by these

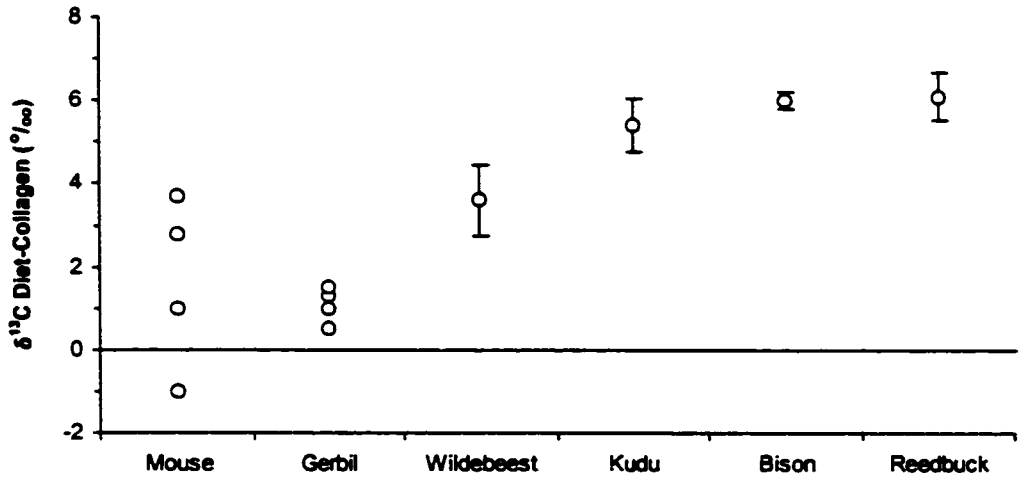


Figure 28. **Stable carbon isotope composition of bone collagen (obtained via comparable extraction procedures) relative to diet for samples of several modern terrestrial mammals.** Here, dietary $\delta^{13}C$ (estimated for the free-ranging herbivores) is standardized to 0 °/oo; enriched samples have positive values and depleted samples have negative ones. Error bars indicate single standard errors for multiple individuals, available for free-ranging herbivores only. Data from Ambrose and Norr (1993), Bender et al. (1981), DeNiro and Epstein (1978), Sillen (1988), Tieszen (1994) and Vogel (1978).

animals; others speculated that this variation might be due to differences in the isotopic composition of the protein component of the diet (e.g., Krueger and Sullivan 1984; van der Merwe 1982). Whatever the reason for these differences, most researchers who want to reconstruct quantitatively the proportions of C_3 and C_4 plants in an animal's diet, for example, simply assume a "collagen enrichment

factor" of roughly +5 ‰ (e.g., Chisholm et al. 1982; Tieszen et al. 1989; van der Merwe 1982).

Another noteworthy observation to be made from Figure 28 is the considerable variation shown within taxa raised on different diets. Consider, for example, the isotopic composition of gerbil collagen. Since these data were collected for different dietary groups by the same principle investigator, differences in sample preparation and measurement should not be at issue. Similarly, within that taxon, the variation cannot be explained by differences in metabolic rate. Thus, differences in the isotopic composition of components of the diet are likely relevant to an explanation of why the isotopic composition of the collagen varies so.

Another line of evidence against the linear-mixing model is that the isotopic relationship between collagen and bioapatite appears to differ among taxa. Figure 29 shows differences in the isotopic composition of collagen and bioapatite for a few taxa of modern terrestrial mammals. Although researchers (e.g., Krueger and Sullivan 1984; Lee-Thorp et al. 1989) note that the spacing between collagen and bioapatite isotope ratios differs between herbivores and carnivores (for herbivores, the spacing is roughly 7 ‰ and for carnivores, it ranges from 3 to 5 ‰), there are no specific data on modern carnivores published by which to evaluate this. It is unfortunate that, of the relevant data cited in this regard, most is drawn from archaeological specimens; post-depositional alterations to the mineral and organic fractions are a potential source of error that should be avoided in baseline studies such as this.

Controlled-Feeding Experiments using Rodents

The two models of carbon metabolism were recently tested by controlled-feeding experiments using rats (Ambrose and Norr 1993) and mice (Tieszen and Fagre 1993b). The two studies, although similar in intent, used different research designs, particularly in regards to diet. The rat diets (Ambrose and Norr 1993) were composed of biochemically pure components (e.g.,

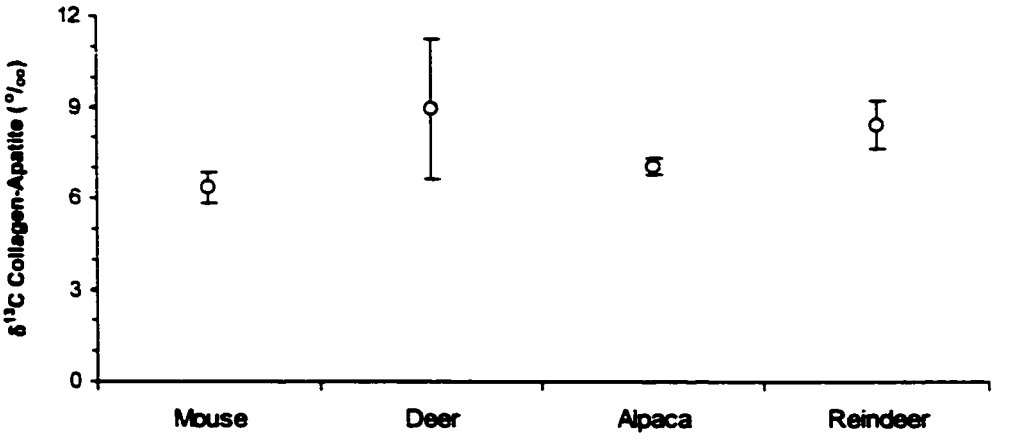


Figure 29. **Mean difference (± 1 sd) in the stable carbon isotopic composition of collagen and bioapatite for some terrestrial mammals.** Data from Cormie and Schwarcz (1994), DeNiro and Epstein (1978), Nelson et al. (1986), and Schoeninger and DeNiro (1982).

beet sugar, soy protein, casein), while the mouse diets (Tieszen and Fagre 1993b) were composed of common ingredients (e.g., soybean meal, ground wheat). The former approach made isotopic determinations of the different biochemical fractions more precise than the latter. Although Ambrose and Norr simply measured the isotope ratios of their purified ingredients, Tieszen and Fagre had to chemically extract different fractions; because their extraction process could not isolate the total dietary protein in a diet, Tieszen and Fagre calculated the isotope value of the protein component of each diet using the nitrogen concentration in each diet and estimates of the isotope value of their various protein sources. Tieszen and Fagre sought to create diets which were comparable in terms of nutritional adequacy and thus avoid complications due to nutritional stress (although two diet groups failed to gain as much weight as the rest and one group did not reproduce). In contrast, Ambrose and Norr varied the protein content of their rats' diets from 5% to 70%; they had to adjust the compositions of two low-protein diets because reproductive female rats on those diets consumed their young. Finally, Ambrose and Norr manipulated their dietary components to produce a wider range of differences in the

isotopic composition of dietary fractions (e.g., protein $\delta^{13}C$ values differed from the whole diet by as little as 1.1 ‰ and by as much as 14.2 ‰) than Tieszen and Faegri's diets (e.g., protein $\delta^{13}C$ values differed from the whole diet by as little as 0.1 ‰ and by as much as 6.2 ‰).

Figure 30 plots the isotopic relationship between bioapatite and whole diet for rats and mice. There is a strong positive linear association between stable carbon isotope ratios of bioapatite and diet over a broad range of isotopic diets. The isotopic composition of bioapatite is thus a strong predictor of bulk dietary consumption. This result requires a slight adjustment to the isotope-routing model, which, in its initial form (Krueger and Sullivan 1984), posited that the isotopic

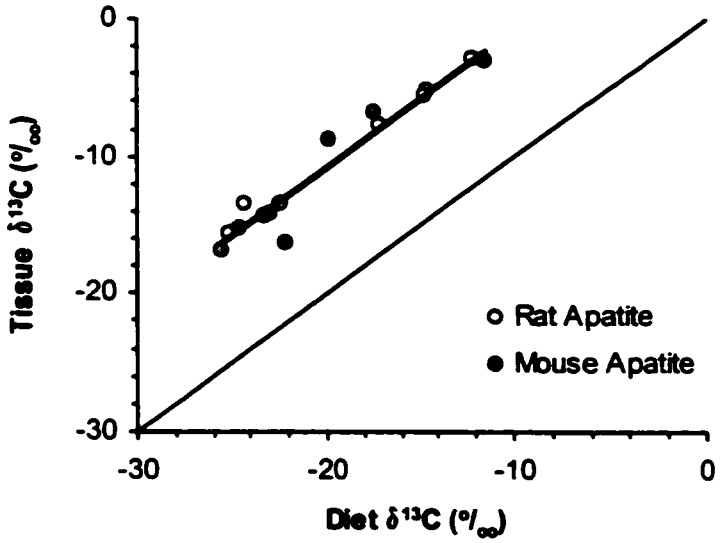


Figure 30. **Isotopic relationship between bioapatite and whole diet in rats and mice.** The thin diagonal line plots a hypothetical 1:1 relationship between diet and tissue; the thick line plots a linear regression line for the collected data ($r = .970$; $p < .001$). Error terms are smaller than the symbols plotted and thus are not visible. Data for the rat are from Ambrose and Norr (1993) and for the mouse are from Tieszen and Fagre (1993b).

composition of bioapatite would reflect primarily the carbohydrate and lipid components of the diet. Now, it is recognized that dietary protein in excess of amounts necessary for protein synthesis is utilized for energy purposes as well, and consequently it also contributes to the isotopic compositions of blood bicarbonate and ultimately bone carbonate.

Comparing Figure 30 with Figure 31a shows that the rodent collagen isotope ratios are less directly related to the isotopic composition of the bulk diet (r = .656; p = .008) than are the bioapatite ratios. Figure 31b plots the rodent collagen isotope ratios against dietary protein and the relationship is improved (r = .774; p = .001). Particularly interesting, however, is the observation that the mouse collagen

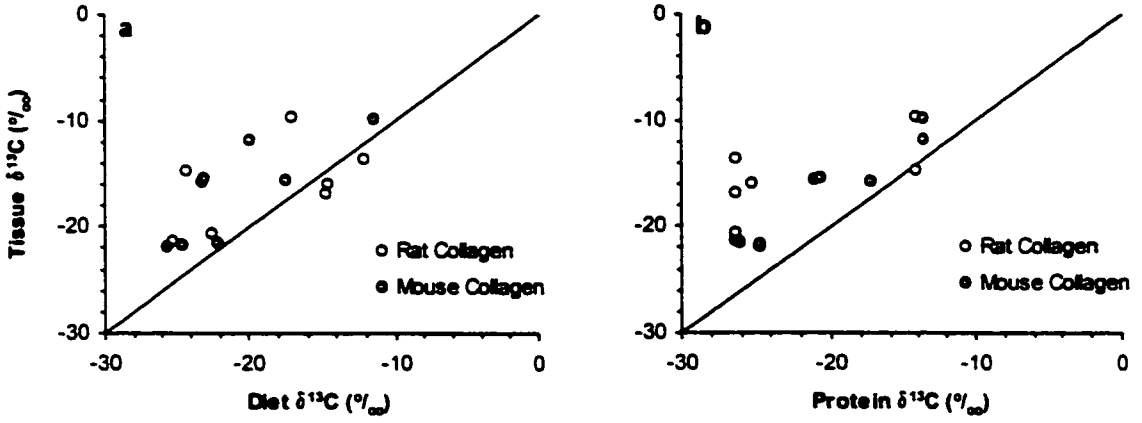


Figure 31. **Isotopic composition of collagen relative to the isotopic composition of (a) the whole diet and (b) dietary protein.** The thin diagonal line plots a hypothetical 1:1 relationship between diet and tissue. Data for the rat come from Ambrose and Norr (1993) and for the mouse come from Tieszen and Fagre (1993b).

isotope ratios are systematically related to the isotopic composition of the dietary protein (r = .954; p < .001), while the rat collagen ratios are more variable (r = .678; p = .094). This appears to be a function of the differences in protein content and isotopic composition of the protein fraction versus the whole diet.

To explore the patterning in Figure 31b above, I turned to an examination of how collagen responds to variation in dietary components. Figures 32a and 32b show the influence of dietary protein content and the isotopic difference between the protein component of the diet and the whole diet on the composition of collagen relative to the diet. In Figure 32a, the isotopic composition of collagen relative to dietary protein is strongly related to the difference between the protein component of the diet and the whole diet ($r = -.943$; $p < .001$). When the protein is

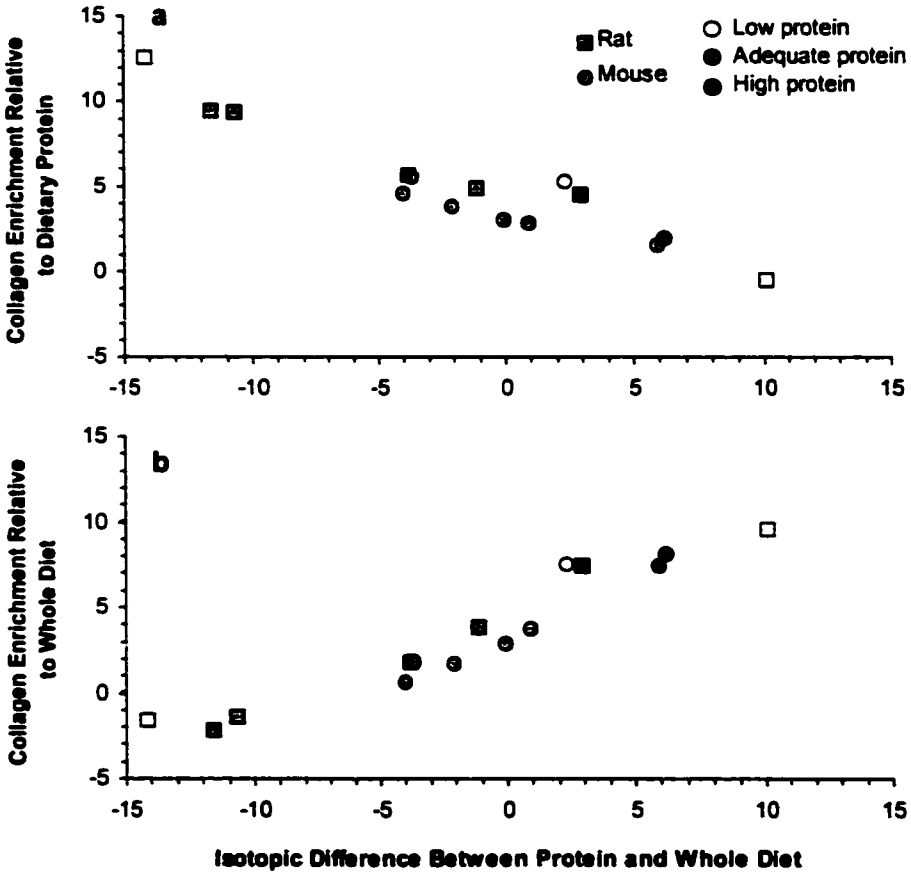


Figure 32. **Influence of dietary protein content and isotopic composition of dietary protein relative to whole diet on the isotopic relationship between collagen and (a) dietary protein and (b) whole diet.** Symbol shape indicates taxon; symbol fill indicates protein content.

depleted relative to the remainder of the diet, the collagen is enriched positively as some nonprotein biochemicals are used in collagen synthesis; this is particularly true of diets with low protein content and with severely depleted protein sources. When differences between the protein and non-protein components of the diet are minor, there appears to be a fractionation effect that enriches the content of the collagen by 3 - 5 ‰. When the protein is enriched relative to the rest of the diet, other relatively depleted fractions contribute to collagen synthesis, with a net effect of little or no enrichment. Overall, these data suggest that the relative isotopic composition of the protein and nonprotein components of the diet is the most important factor in determining the degree of collagen enrichment over dietary protein. With the data at hand, it appears that low protein diets only bring such a pattern to an extreme.

Similarly, Figure 32b looks at how those two factors (protein content and isotopic composition of protein relative to whole diet) affect the isotopic composition of collagen relative to that of the whole diet. Again, there is a strong relationship ($r = .956$; $p < .001$), but this time it is positive. The low protein diets on either end, which are most influenced by the composition of the whole diet, almost hint at an s-shaped relationship; presumably diets with adequate protein at the extremes would "straighten" the ends of a regression line. When the isotopic composition of the dietary protein is depleted relative to the rest of the diet, collagen is depleted relative to the whole diet. When there are only minor differences between the two, collagen is enriched 2 - 4 ‰ as documented in several small animal laboratory studies. When the dietary protein is enriched relative to the whole diet, the isotopic composition of the collagen is enriched relative to that of the whole diet. Of course, low protein diets, which require input from nonprotein components of the diet in collagen synthesis, may moderate this pattern.

The conclusion to be drawn from these controlled-feeding studies is that the isotopic relationship between an animal's tissues and its diet cannot be

accounted for by a simple linear-mixing model. In rodents at least, variation in the isotopic composition of the two phases of bone is best accounted for by the isotopic-routing model. The isotopic composition of bioapatite is strongly related to the isotopic composition of the whole diet, while collagen has a more variable relationship with the whole isotopic diet. Although collagen appears to reflect primarily the protein component of the diet, its $\delta^{13}C$ value is influenced in patterned ways by the isotopic composition of other dietary components and the protein content of the diet.

Because the biochemical sources and metabolic processes involved in the synthesis of the organic and mineral phases of bone differ, it makes physiological sense that they would each provide different kinds of information about dietary intake. However, the appropriateness of the rodent model for understanding the human situation is questionable on physiological grounds. It is not just a matter of scaling for body size or metabolic rate (Benevenga 1986). The digestive system of an animal functions to meet the requirements for the digestion and absorption of its particular diet (Argenzio 1984b). Variation in the digestive and absorptive regimes among different taxa[24] has implications for nutrient metabolism; as the particular biochemical reactions, products and rates differ, so may the isotopic relationships between diet and tissues. Clearly, then, one cannot use just any animal as a model for digestion, absorption and tissue synthesis in human beings. Even though they are both omnivores, the gastrointestinal tracts of

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[24] Carnivores, for example, rely almost exclusively on enzymatic digestion of carbohydrates, proteins and fats in the small intestine to form soluble sugars, peptides or amino acids, and fatty acids, respectively; the large intestine is relatively unimportant (Argenzio 1984a, 1984b; Bastianelli et al. 1996). Although protein and some carbohydrate digestion also occurs in the small intestine of herbivores, these animals depend primarily upon microbial cellulose digestion in the large intestine to convert carbohydrates to volatile fatty acids; proteins that reach the large intestine are degraded to nonprotein nitrogen products (urea and ammonia) for use by microorganisms and/or for absorption (Argenzio 1984a; Bastianelli et al. 1996).

rodents differ from humans in both size and function (Hanson et al. 1986) and they metabolize protein quite differently (Young and Bier 1981). Thus, rodents, while experimentally convenient, are not the best choice for a study of this type.

Controlled-Feeding Experiments using Pigs

While pigs play an important role in many aspects of biomedical research (Bustad 1966; Bustad and McClellan 1966; Mount and Ingram 1971; Tumbleson 1986b; Tumbleson and Schook 1996), one of their greatest uses is in nutritional studies, including assessments of nutrient requirements, digestion, absorption and metabolism. Like people, they are omnivores; their digestive tracts are physiologically and anatomically similar to those of people, as are their nutritional requirements. Thus, pigs provide an excellent nutritional model for humans (e.g., Ball et al. 1996; Benevenga 1986; Fleming and Arce 1986; Kien et al. 1997; Pond and Houpt 1978; Reeds and Odle 1996; Tumbleson 1986a).

Hare and colleagues (1991) raised two groups of domestic pigs on different diets, one a pure C_3 diet ($\delta^{13}C$ = -25.3 ‰) and the other a pure C_4 diet ($\delta^{13}C$ = -12.4 ‰) to assess the degree of fractionation associated with collagen synthesis. They reported that collagen was enriched over the whole diet by 1.4 ‰ for the pigs raised on the C_3 diet and by 3.0 ‰ for those raised on the C_4 diet. Although these values are less than the oft-cited +5 ‰ collagen enrichment factor based primarily on large herbivores, they are not out of the range documented in laboratory experiments. Hare et al. speculate, however, that the pig collagen may exhibit less enrichment than the field animals because of the pigs' age and growth status. The pigs in their study were juveniles and still growing rapidly. In that case, protein synthesis rates were high, with little turnover and relatively low rates of reuse of resorbed amino acids that might result in additional fractionation. An additional factor may be the length of time the pigs were on their diets; although Hare et al. do not report how long that was or what the pre-experiment isotopic diet

was, that their pigs' weights increased only 6-fold suggests they may not have been completely equilibrated (Schroeder and Ben-Ghedalia 1986).

More interesting, however, Hare et al. isolated individual amino acids in the source diets and in the collagen and measured their $\delta^{13}C$ values. They showed that dietary amino acids vary greatly in isotopic composition, that they often have greatly enriched $\delta^{13}C$ values in collagen, and the pattern of amino acid enrichment does not differ between C_3 and C_4 diets, or when compared with other taxa. Substantial fractionation occurs during amino acid metabolism and collagen synthesis and this may well account for the generally-noted isotopic enrichment of collagen over the consumed diet and also for the isotopic enrichment of collagen over the protein component of the diet.

To expand upon Hare et al.'s work (among other goals), I had twenty pigs raised in controlled circumstances (confined to an indoor, environmentally-controlled habitat) at the Swine Research and Teaching Facility, Washington State University, Pullman, WA. At eight weeks of age, the twenty piglets were randomly divided into four feed groups of five pigs each. The feeds, which were composed of common ingredients, differed in their isotopic composition of protein and energy sources: 1) C_3 energy and protein sources; 2) C_3 protein and C_4 energy sources; 3) C_4 energy and C_3 protein sources; and 4) C_4 energy and protein sources. At nine months of age, the pigs were sacrificed and bone samples were collected for isotopic analysis. The planned analyses are not complete; however, here I present partial results that are relevant to this examination of the relationship between collagen and isotopic diet. Detailed information about the design of this aspect of the experiment and the relevant results are presented in Appendix C.

Figure 33a shows the close isotopic relationship between collagen and whole diet for the pig experiment. Unlike the figures shown for rodents, in this plot and in the others that follow, each symbol represents an individual animal. In contrast to the rodents (Figure 31a), the collagen of these pigs is strongly related to

the composition of the whole diet. There is also a close relationship between collagen and dietary protein (Figure 33b).

To see if pig collagen responds similarly to rodents with respect to variation in the isotopic composition of dietary protein relative to the whole diet, plots like those for rodents were generated. Figure 34a shows the isotopic composition of collagen relative to estimated $\delta^{13}C$ values for dietary protein (see Appendix C) versus the difference in isotopic composition between dietary protein and the whole diet. As in the rodents, a strong negative relationship obtains (r = -.980; $p < .001$). When dietary protein is isotopically depleted, collagen will be enriched due to some input from the rest of the diet; when dietary protein is enriched, collagen will be less enriched due to biochemical contributions by the rest

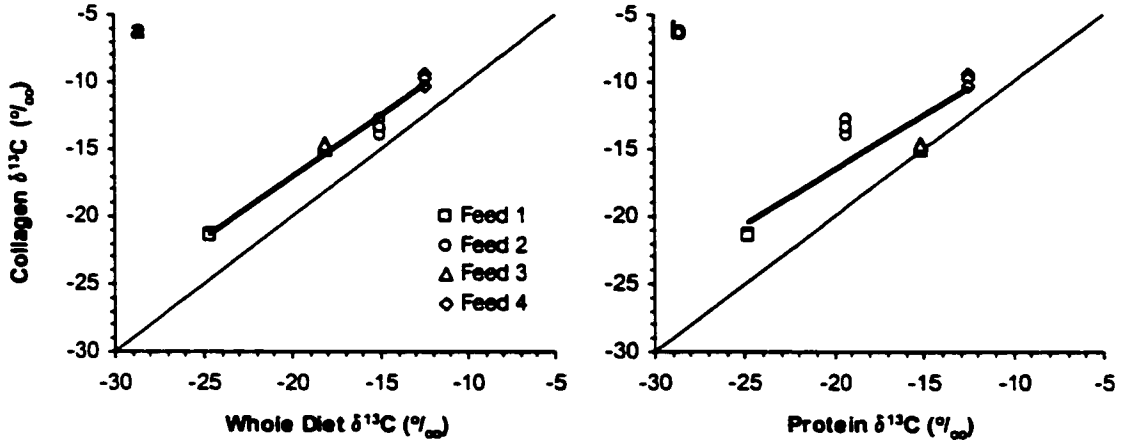


Figure 33. **Isotopic composition of pig collagen relative to the isotopic composition of (a) the whole diet and (b) dietary protein.** The thin diagonal lines plot hypothetical 1:1 relationships between diet and tissue; the thick lines plot linear regression lines for those data (collagen vs. whole diet, r = .989, $p < .001$; collagen vs. dietary protein, r = .903; $p < .001$).

of the diet; and when there is little difference between dietary protein and the rest of the diet, collagen appears to be enriched over dietary protein by about 3 ‰. As Figure 34b shows, the opposite relationship is obtained when the difference between collagen and the whole diet is examined (r = .854; $p < .001$).

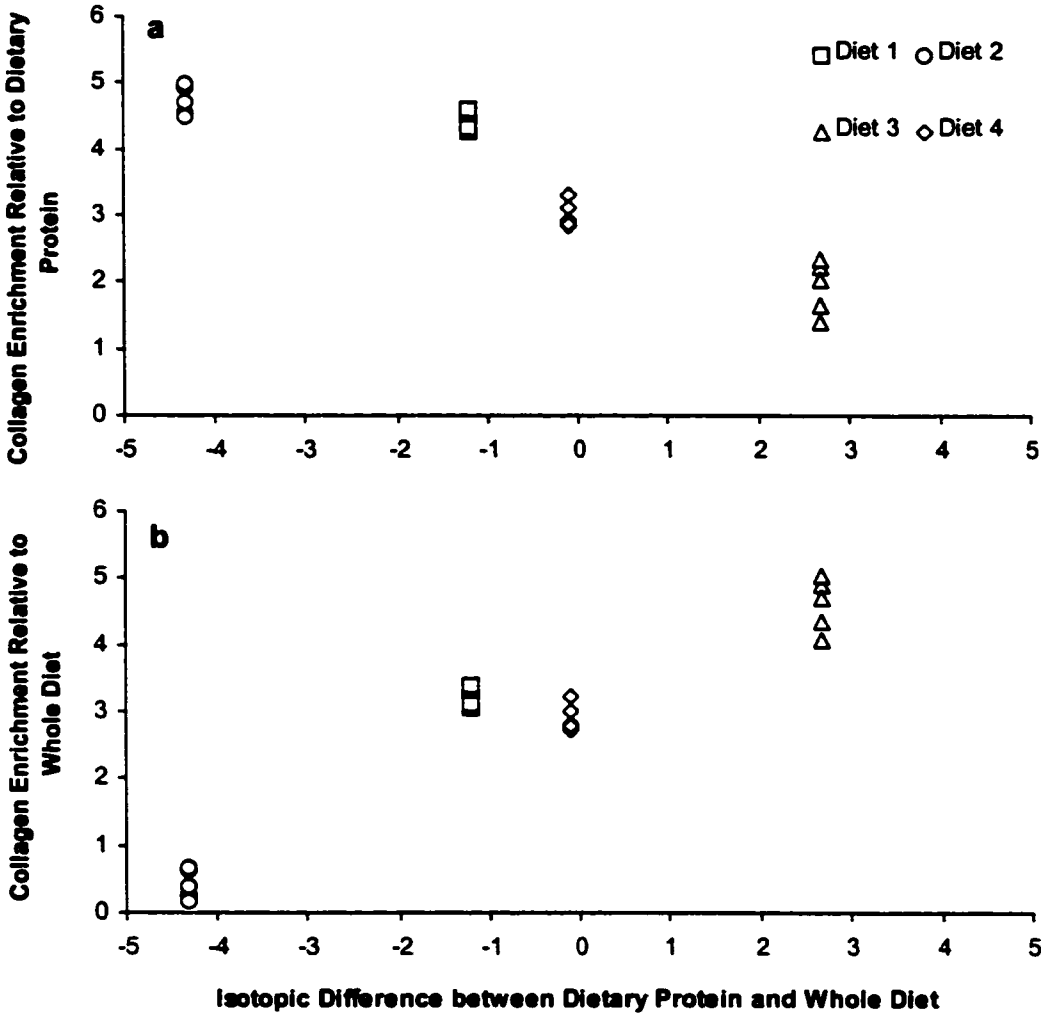


Figure 34. **Influence of isotopic composition of dietary protein relative to whole diet on the isotopic relationship between collagen and (a) dietary protein and (b) whole diet in pigs raised on different diets.**

Implications of the Controlled-Feeding Studies

The controlled-feeding experiments demonstrate that the stable carbon isotopic composition of bioapatite is explained well by the isotopic composition of the whole diet. In contrast, the $\delta^{13}C$ values of collagen are generally better explained by the isotopic composition of protein than by the whole diet; the best results are obtained when the isotopic difference between dietary protein and

whole diet and the quantity of dietary protein are considered. Protein quality is another, as yet unstudied, variable which may be relevant. It is important to note, however, that the severe deviations between collagen and dietary $\delta^{13}C$ values occurred when rodents consumed grossly inadequate (as indicated by reproductive failure) and/or isotopically extreme diets. In diets not characterized by nutritionally or isotopically extreme conditions, collagen appears to reflect the isotopic composition of the whole diet quite well. Diets consumed by free-ranging organisms, including human beings, are probably not as isotopically unbalanced as the artificially-created rat diets, nor are they as nutritionally inadequate, or their lineages would have disappeared long before.

It is important to recognize, too, that the range of potential diets in any "natural" setting is more limited than that of the experimental settings. Thus, the degree of complexity in diet-tissue relationships may be reduced. In the interior Eastern Woodlands, for example, the probability of diets with C_4 protein and C_3 carbohydrate bases is extremely low. Maize, the predominant C_4 resource in the area, is an excellent source of carbohydrates but is renowned as a poor protein source. It is relatively low in protein compared to other cereals and it is a poor-quality protein, being particularly deficient in two essential amino acids, lysine and tryptophan (Dowswell et al. 1996; FAO 1970; Tuross and Fogel 1994). The amino acid deficiencies can be compensated by consumption of C_3 complementary proteins like those in beans (Kaplan 1971; FAO 1970) or meat, or they can be lessened by alkali processing techniques (Katz et al. 1975).

When the controlled-feeding experiments are similarly constrained (i.e., the C_4 protein/C_3 carbohydrate diets are removed), the isotopic relationship between collagen and whole diet is much simplified (Figure 35). The slopes and intercepts of least-squared regression equations of diet-tissue relationships for different animal models appear to differ, but their 95% confidence intervals overlap. With all animals combined, the diet-tissue relationship is strongly significant (r =

.941; $p < .001$). Flatness at the C_3 end of the diets reduces the linearity of the relationship, though, and consequently, it is slightly better described by a second order polynomial ($R^2 = .906$). The point is that, in a "natural" setting like the Eastern Woodlands, the isotopic composition of bone collagen should follow closely the isotopic composition of the diet.

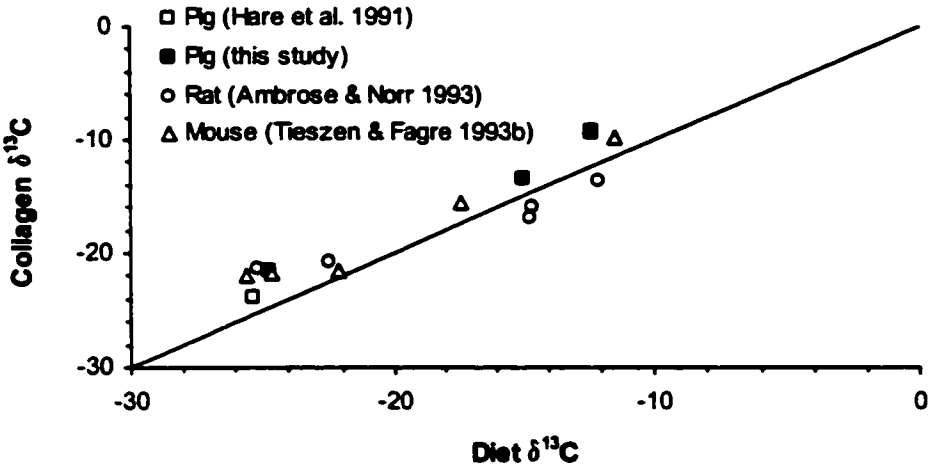


Figure 35. **Isotopic composition of collagen relative to the isotopic composition of whole diet for a limited sample of controlled-feeding studies.** The thin diagonal line plots a hypothetical 1:1 relationship between diet and tissue.

Two main interpretive problems are introduced by the isotopic-routing model. The first problem involves our ability to recognize isotopically when a small amount of maize has been consumed in a predominantly C_3 diet, such as might have occurred for the few hundred years after the initial introduction of maize into the area but prior to its becoming a dietary staple. Under such conditions, the consumption of small quantities of low-protein maize may not be identifiable in bone collagen because more complete proteins (like those supplied in animal meats) would be the preferred amino acid source for collagen. In low-protein diets where C_3 resources predominate, carbohydrates and/or lipids from the C_3 dietary base would be necessary for collagen synthesis, again leading to

underrepresentation of the C_4 component. Since maize would be isotopically underrepresented in collagen under those conditions, it has been argued that bioapatite would be more appropriately analyzed (Ambrose 1993; Ambrose and Norr 1993; Hart 1999a). In eastern North America, two studies using bioapatite $\delta^{13}C$ values have sought evidence of low-level maize consumption in pre-maize farming populations where collagen $\delta^{13}C$ values indicated a lack of maize (Katzenberg and Harrison 1999; Schober and Ambrose 1995); in neither case did the bioapatite data provide a solution different from that of the collagen data.

The second problem introduced by the isotopic-routing model involves assessing the relative contribution of maize to the bone collagen of people for whom it was a dietary staple. If maize was the dominant source for both the energy and protein components of the diet, then the $\delta^{13}C$ values of collagen will be an accurate reflection of the amount of maize consumed. If, however, maize was the primary energy source and C_3 fauna were the dominant protein source, then the amount of maize consumed will be underestimated by the isotopic composition of the bone collagen. A low protein diet would actually ameliorate this situation somewhat because the C_4 energy fraction would contribute carbon to protein synthesis. It is unlikely that isotopic routing could cause maize consumption to be overestimated from analysis of collagen $\delta^{13}C$ values.

Again, $\delta^{13}C$ analysis of bioapatite might allow archaeologists to establish whether or not maize consumption is underrepresented in bone collagen. Two studies which compared collagen and bioapatite $\delta^{13}C$ values for Eastern Woodlands maize farmers (Conard 1988; Katzenberg and Harrison 1999) have not found evidence to suggest that the isotopic composition of dietary protein is significantly different from that of the whole diet. Thus, in those samples, at least, collagen $\delta^{13}C$ values do not appear to be underestimating maize consumption. A third study (Schober and Ambrose 1995) compared bioapatite and collagen $\delta^{13}C$ values for individuals from an elaborate burial situation at Cahokia; their

preliminary results did suggest that maize consumption was underrepresented in the collagen of these individuals. Other isotopic work on that burial context (Buikstra et al. 1994) has indicated that collagen preservation is a serious problem there and thus evaluation of Schober and Ambrose's work should await a complete report. A fourth study (Wilson 1997) reported $\delta^{13}C$ values for bioapatite and collagen from Late Prehistoric burials from the Western Lowland of Missouri. The isotopic composition of these individuals varied substantially. Differences between the two bone fractions indicate that the collagen of most (76%) individuals may underestimate the amount of maize consumption, while it overestimates maize consumption for 18% of them. Wilson, however, suggested that preservation may be a problem among some of those samples, as well.

Because isotopic diet is apparently recorded more faithfully in the bioapatite than in the collagen fraction of bone, isotopic analysis of bioapatite would seem to be the best choice for documenting the role of maize in prehistoric diets. Archaeologists recognize, however, that the carbonate in bioapatite is susceptible to post-depositional alterations. Although recent advances in sample processing and evaluation have made isotopic analysis of bioapatite slightly less worrisome (and tooth enamel even less so), temperate environments are not conducive to bioapatite preservation. Thus, we cannot simply assume that bioapatite $\delta^{13}C$ values indeed reflect the original isotopic signature of the carbonate fraction of bone mineral and, as I will show later, there is reason to question the integrity of bioapatite in at least some of the samples examined here. Collagen provides a suitable material for analysis of isotopic diet and it tends to be more stable in the post-depositional environment. Thus, collagen was the material analyzed in this research and further discussion is limited to that fraction of bone.

Sources of Isotopic Variation

With the general pattern of isotopic fractionation associated with diet, metabolism and tissue synthesis established, it is important to consider what other

factors may introduce variation into the isotopic record of dietary change. First, I consider isotopic variation introduced into the study of archaeological skeletal populations by sample preservation and by sample selection, preparation and measurement. Next, I turn to metabolic, environmental and behavioral sources of isotopic variation. There are many ways to structure such a discussion; here, it makes sense to distinguish potential isotopic variation that may occur in spite of consuming identical diets and variation that may occur as a result of dietary differences.

Sample Preservation

As bone interacts chemically with the surrounding burial environment, the organic fraction deteriorates. Collagen becomes fragmented and "leaches" away, with some residues being preferentially retained as a result of charge interactions with the calcium-phosphate crystals. As a result, the total protein content drops and the relative amino acid composition changes. At the same time, exogenous contaminants (e.g., humates) can bond chemically with the degraded protein fragments. The noncollagenous proteins (e.g., glycoproteins, immunoglobulins, albumin, osteocalcin) in bone tend to be more resistant to degradation than collagen, perhaps because they are more closely associated with the mineral phase of bone (Weinstock and Leblond 1973). Tuross et al. (1989) found that the noncollagenous-protein content of extracted bone proteins declined with time after death, but this was apparently a function of the input of increased collagen fragments. As the collagen continues to deteriorate and is removed from the bone, amino acids from more stable noncollagenous proteins may come to dominate the endogenous protein remnants (Masters 1987; Tuross 1989, 1991, 1993; Weiner and Bar-Yosef 1990; contra Hedges and Wallace 1980).

Because collagen has likely experienced profound changes since the organism's death, the residue or extract that archaeologists end up with following their extraction procedures is not usually collagen in a strict sense. The product is

mostly derived from collagen, but may also contain varying amounts of other endogenous biological (fats, lipids, noncollagenous proteins), exogenous organic (humic and fulvic acids, other organics), and exogenous inorganic (clay minerals, salts) materials. Additionally, it may have experienced differential loss or preservation of amino acids as the collagen deteriorated. To reflect its different chemistry, I refer to the extracted material as "collagen" (cf. Ambrose 1990; DeNiro and Weiner 1988) or collagen extract.

Since the various endogenous and exogenous organic constituents of "collagen" may have different stable carbon isotope ratios, the degree to which the "collagen" has been altered by postmortem processes will influence its accuracy as an indicator of diet. In some cases, the $\delta^{13}C$ value of the extracted material will not accurately reflect the original biological signature. For example, the inclusion of soil humic substances (a common source of "collagen" contamination), which generally reflect the isotopic composition of the local flora (Ambrose and Sikes 1991), may alter the isotopic signal variably depending upon the difference between the local vegetation and the organism's collagen and the amount of contamination involved (Ambrose and Norr 1992). Thus, it is critical to assess sample quality through examination of attributes such as extract yield, C/N ratios, carbon and nitrogen concentrations, and amino acid composition. Below, I consider "collagen" quality for samples from middle and upper Ohio Valley populations with previously acquired stable carbon isotope data (Figure 36). Data by which "collagen" integrity can be evaluated are not available for all samples.

Extract Yield

About 22% of modern bone is organic by weight. Roughly 90% of that is collagen, so bone is roughly 20% collagen. The amount of "collagen" remaining in archaeological bones is highly variable, however, and depends on the nature of post-depositional processes. Empirically, there appears to be a threshold of about 2%; often when the yield of "collagen" extracted from archaeological materials is 2% or

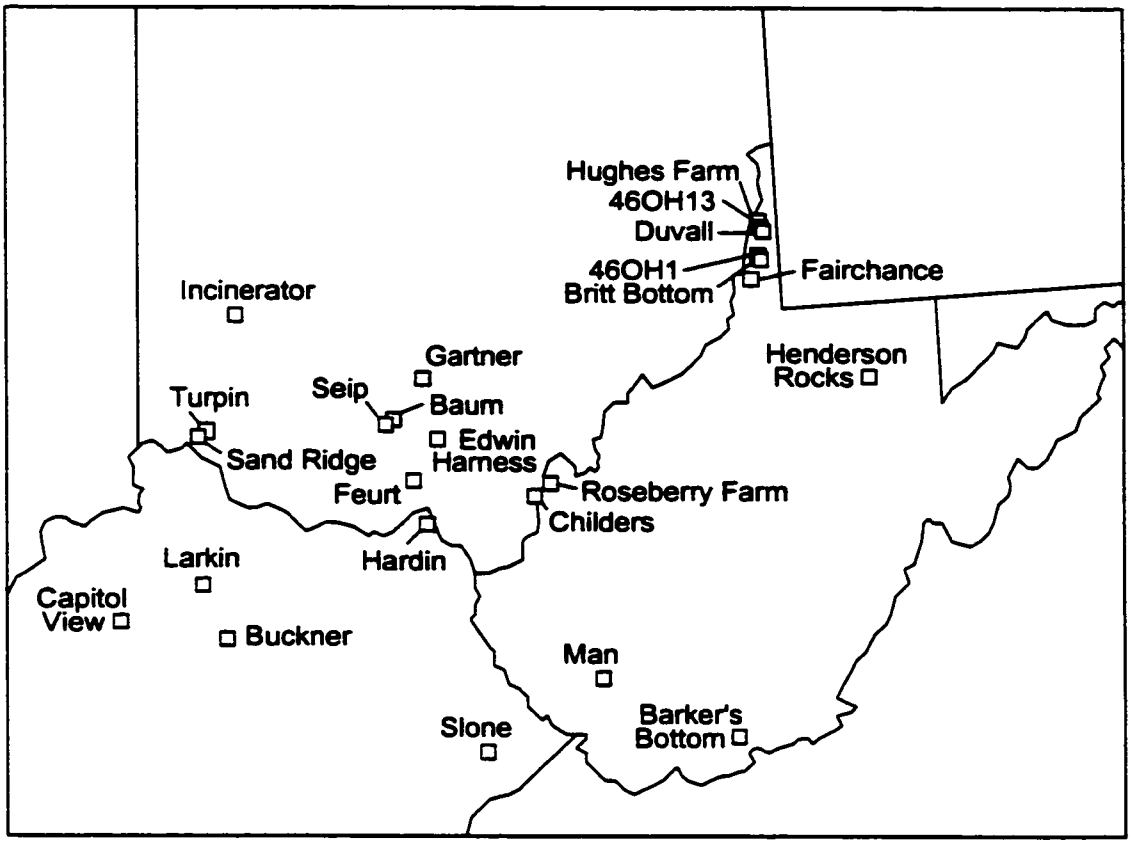


Figure 36. **Location of Ohio Valley populations with stable carbon isotope data.**

less, other indicators (e.g., C/N ratios, amino acid composition) suggest that the bone is significantly altered and the extract is no longer representative of its original composition (Ambrose 1990; DeNiro and Weiner 1988). This observation may simply reflect that when "collagen" yields are that low, small amounts of noncollagenous proteins or other contaminants can make substantial contributions to the composition of the extract.

Extract yield information is presently available for 77 samples from seven locales (Baum, Feurt, Gartner, Incinerator, Capitol View, Buckner and Larkin [Schurr 1998; Schurr and Schoeninger 1995]). The average (± 1 SD) yield for those samples is 9.29 ± 5.87 %, indicating that sufficient "collagen" was recovered

from most individuals for reliable isotopic measurement. Overall, the distribution of samples tends to be biased toward low yields (Figure 37), with more samples having lower yields than expected in a normal distribution ($Z = 1.971$; $p = .001$). Among these samples, three individuals lie below the 2% empirical threshold. Rather than omit them from further consideration on the basis of poor extract recovery, however, they should be closely scrutinized with respect to the other measures of sample integrity. If those three samples fail to meet the other criteria, they should be disregarded.

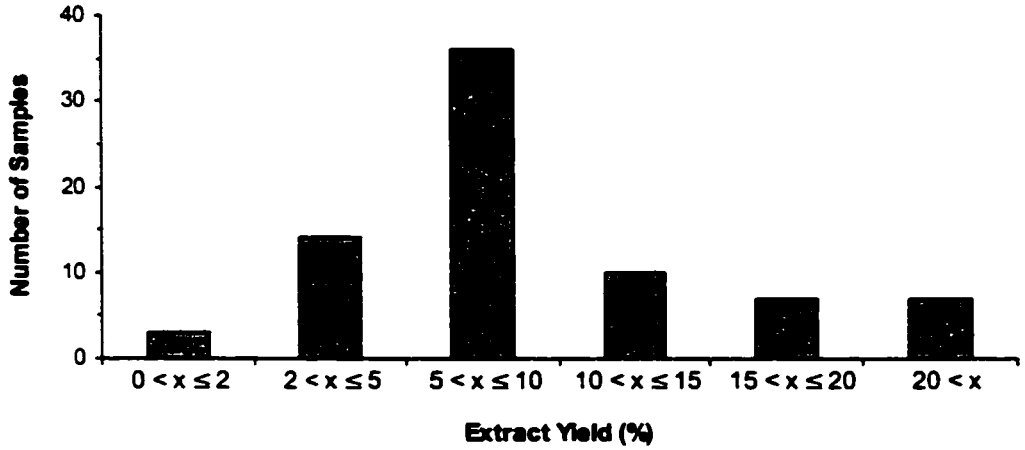


Figure 37. **Extract yield data for a subsample of previously-analyzed individuals from middle and upper Ohio Valley locales.**

Carbon and Nitrogen Composition

By weight, collagen in modern bone is approximately 45% carbon (range 15.3 – 47.0%) and 15% nitrogen (range 5.5 – 17.3%) (Ambrose 1990) and has atomic C/N ratios ranging from 2.9 – 3.6 (DeNiro 1985; Nelson et al. 1986; Schoeninger and DeNiro 1984). These parameters are potential indicators of the integrity of the "collagen" extracted from archaeological bones and measures of the degree to which inorganic and organic impurities are included in these extracts. Indeed, C/N ratios outside the reported modern range often have aberrant stable isotope ratios. In arguing against the exclusive use of C/N ratios for assessing "collagen" integrity, seemingly good samples with C/N ratios fortuitously within the

"acceptable" range and high apparent yields (due to incomplete removal of inorganic residues) should be identifiable as diagenetically altered on the basis of low C and N concentrations (Ambrose 1990; Greenlee 1990).

Again, turning to the previously-collected Ohio Valley isotope sample, C/N ratios are available for 88 individuals (Greenlee 1990; Schurr 1998; Schurr and Schoeninger 1995) from twelve locales (Baum, Feurt, Gartner, Incinerator, Capitol View, Buckner, Larkin, Duvall, Britt Bottom, 46OH1, Roseberry Farm and Henderson Rocks). The C/N ratios for 71 (81%) of the individuals are within the range expected for collagen, while nine are too low and eight are too high. Figure 38 plots the C/N data against extract yields for those samples with both kinds of information. This plot suggests that the C/N ratios are not distributed similarly with respect to "collagen" yield; high C/N ratios are restricted to low-yield samples, while those within the range and those that are too low are distributed throughout. This is confirmed by a Kruskal-Wallis test comparing the distribution of the ratios (low [$x < 2.9$], acceptable [$2.9 \leq x \leq 3.6$] and high [$x > 3.6$]) across "collagen" yield ($\chi^2 = 22.872$; $p < .001$). The three samples with "collagen" yields below 2% have the highest C/N ratios. At least two processes are thus indicated, only one of which is correlated with the total yield of "collagen" in a bone.

Figure 39 plots stable carbon isotope data (as deviations from the mean of the relevant locales) versus C/N ratios for those samples outside the range of 2.9 – 3.6. Samples with low C/N ratios tend to be enriched, while those with high ratios tend to be depleted. The latter extracts probably include soil humic materials, which have high C/N ratios and negative $\delta^{13}C$ values (reflecting the C_3 vegetation that predominates in this region) relative to bone. The three samples with the lowest (< 2%) yields and highest C/N ratios show the greatest negative deviation. Thus, the individuals with low "collagen" yields are problematic in terms of their elemental and isotopic compositions and their removal from further consideration is clearly warranted. The other samples outside the "acceptable" C/N

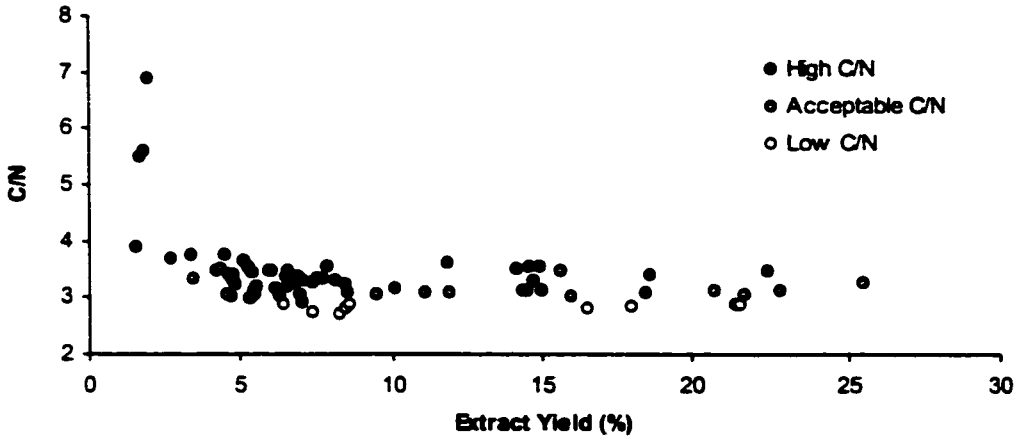


Figure 38. **C/N ratios plotted against "collagen" yields for a subsample of previously-analyzed individuals from middle and upper Ohio Valley locales.**

range are less clearly biased. The most conservative approach would be to omit them from the population of isotope data; a more optimistic approach would be to consider how conclusions might differ when they are included and when they are excluded. Inclusion of these "unacceptable" samples does not significantly alter conclusions about isotopic diet and so they are included.

C/N ratios for all eleven of the samples lacking extract yield data (from Duvall, Britt Bottom, 46OH1, Roseberry Farm and Henderson Rocks) are within the acceptable range (Greenlee 1990). The concentration of carbon in those samples ranged from 41.1 – 44.9 %, consistent with that of collagen.

Amino Acid Composition

Collagen molecules have a unique amino acid composition – about 33% glycine with high amounts (relative to other proteins) of proline and hydroxyproline (Woodhead-Galloway 1980). Because of this, amino acid composition can be a good indicator of "collagen" preservation. The amino acid composition of a poorly-preserved sample may reflect (a) differential loss of amino acids during collagen diagenesis, (b) differential survival of amino acids from

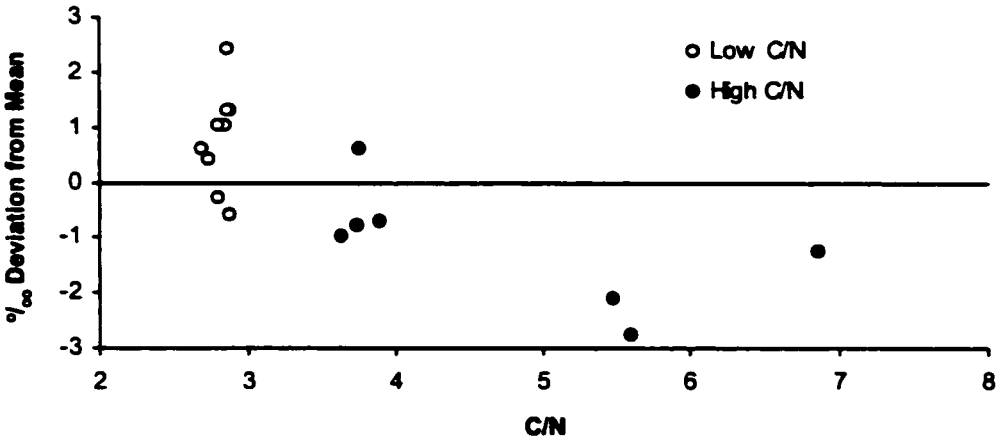


Figure 39. **C/N ratio versus deviation from mean $\delta^{13}C$ for samples with C/N ratios outside the range 2.9 - 3.6.**

noncollagenous proteins, and/or (c) intrusive amino acids from an exogenous source. Although these three factors have varying implications for the success of efforts to date "collagen" using radiocarbon determinations (i.e., only the addition of exogenous amino acids poses a problem because they may not be the same age as the bone), for dietary analyses the consequences are all problematic: the $\delta^{13}C$ value of the "collagen" may be compromised. This is because the amino acids each have different stable isotope ratios (Abelson and Hoering 1961; Hare and Estep 1983; Hare et al. 1991; Macko et al. 1983, 1987; Stafford et al. 1988; Tuross et al. 1988; Winters 1971); when the relative abundance of amino acids in "collagen" changes, the $\delta^{13}C$ value of the extract may be affected.

In Figure 40, I compare the amino acid composition of collagen (from modern bone) with noncollagenous materials, specifically noncollagenous proteins (from modern bone) and exogenous amino acids (from prehistoric bone). Studies have identified systematic changes in the amino acid composition of the protein fraction of bone as it degrades: hydroxyproline and proline are lost; glycine, alanine, and serine decrease; and aspartic and glutamic acids increase (Hare 1980; Masters 1987). These changes are apparent when the compositions of collagen and

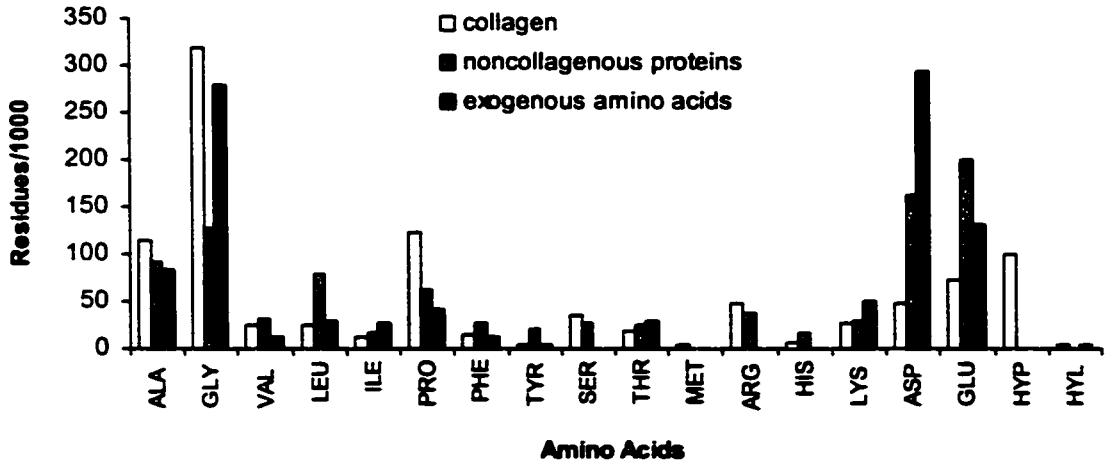


Figure 40. **Amino acid composition of collagen (Woodhead-Galloway 1980) and noncollagenous proteins (Hare 1980) from modern bone, and noncollagenous exogenous amino acids from prehistoric bone (Stafford et al. 1990, 1991).** ALA, alanine; GLY, glycine; VAL, valine; LEU, leucine; ILE, isoleucine; PRO, proline; PHE, phenylalanine; TYR, tyrosine; SER, serine; THR, threonine; MET, methionine; ARG, arginine; HIS, histidine; LYS, lysine; ASP, aspartic acid; GLU, glutamic acid; HYP, hydroxyproline; and HYL, hydroxylysine.

noncollagenous proteins are compared. The composition of exogenous amino acids will, of course, vary with the protein source. As shown in Figure 40, for example, an extract from the Escapule mammoth (Stafford et al. 1990, 1991) exhibits several compositional differences (e.g., high glycine, low glutamic acid) that would not be consistent with changes due to collagen degradation and increasing dominance of noncollagenous proteins as currently understood; the radiocarbon ages of several purified chemical fractions indicate that the Escapule mammoth "collagen" was contaminated by soil humates and amino acids of varying ages.

Of the Ohio Valley individuals with previously-collected isotope data, amino acid compositions are available for only eight from Roseberry Farm and Henderson Rocks (Greenlee, unpublished data). Figure 41 plots the amino acid composition of those "collagen" samples with those of modern collagen, noncollagenous proteins and the exogenous amino acids from the Escapule

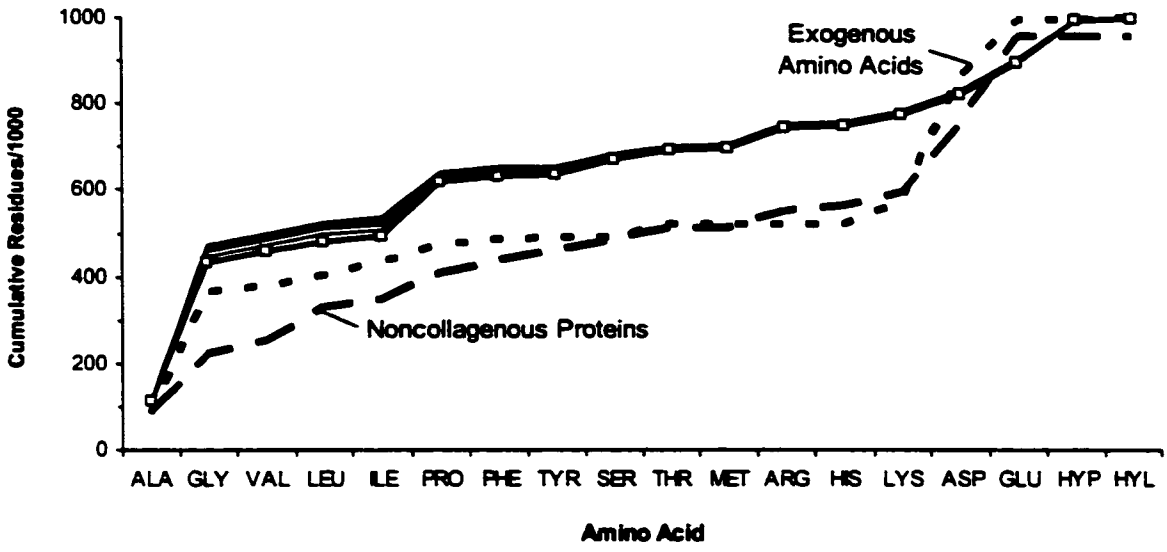


Figure 41. **Amino acid composition of "collagen" from Roseberry Farm and Henderson Rocks.** Archaeological samples (thin black solid lines) are compared to modern collagen (thick black line with □ symbols), modern noncollagenous proteins and exogenous amino acids from prehistoric bone.

mammoth. These archaeological "collagen" samples are quite similar to modern collagen, differing primarily in a greater abundance of glycine. As such, these samples show little evidence of collagen degradation as it has been described (Hare 1980; Masters 1987). The "collagen" appears to be well-preserved.

Sample Preparation and Measurement

The goal of "collagen" extraction for radiocarbon and stable carbon isotope analyses is, of course, to obtain a material containing carbon atoms that (1) are indigenous, (2) are present in measurable quantities, and (3) do not include significant amounts of exogenous carbon (Gurfinkel 1987; Hedges and van Klinken 1992). For many samples, this goal is not easily met. Several approaches to "collagen" extraction are currently in use by different research programs. Unfortunately, efforts (e.g., Chisholm et al. 1983a; Gurfinkel 1987; Liden et al. 1995; Schoeninger et al. 1989; Semal and Orban 1995; Stafford et al. 1987; Tuross et al. 1988) to compare the quality of extracts resulting from different techniques tend

to suffer from one or more problems: (1) small numbers of samples, (2) no replicate analyses to establish error terms, (3) unusual post-depositional situations (e.g., Arctic or arid environments), and/or (4) introduction of minor procedural variations. Although ^{14}C determinations provide the most sensitive comparisons of the products of different extraction protocols, those studies which employ radiocarbon ages to do so do not also evaluate the "collagen" products in other, more accessible, ways so that those results can be integrated with those of other studies. Thus, few analyses are truly comparable and it is difficult to draw conclusions about which techniques might be most effective under particular circumstances.

Here, I am concerned with different extraction protocols that may affect "collagen" $\delta^{13}C$ values obtained from archaeological skeletal populations in the Eastern Woodlands. The techniques used vary according to whether "collagen" was extracted (1) from whole bone or bone powder, (2) using concentrated or diluted hydrochloric acid (HCl), (3) at room or elevated temperature, and (4) with or without soaking in sodium hydroxide (NaOH). Although all of these options have been argued to influence the quantity and quality of "collagen" extracted, the last item, the NaOH soak, is the most controversial with regards to its potential impact on $\delta^{13}C$ values. In Appendix D, I present the results of a limited study comparing three different "collagen" extraction protocols; for a subsample of Ohio Valley skeletal samples, using or excluding the NaOH soak had no significant effect on the isotopic composition of "collagen." Thus, although comparisons of "collagen" $\delta^{13}C$ values among studies generally need to be concerned with systematic differences that correspond to sample pretreatment, the variation in extraction protocols among Ohio Valley analyses is unlikely to have resulted in significantly different outcomes.

Error introduced during sample measurement also must be considered a potential source of isotopic variability. Replicate analyses of CO_2 generated from a homogenous standard can provide information on error associated with mass spectrometry, which is generally negligible compared to error associated

with sample heterogeneity and preparation (assessed through isotopic analysis of replicate "collagen" extractions), which is generally negligible compared to interlaboratory mass-spectrometer calibration error. Maximum interlaboratory error has been estimated to be on the order of 1.0 ‰ (1 SD) (Chisholm 1989; Chisholm et al. 1983a; Mann 1982) and, thus, for interlaboratory comparisons, $\delta^{13}C$ values should vary by more than that to be considered significantly different.

Sample Selection

The chemical composition of different body tissues reflects an average of the diet over varying lengths of time. Labeling studies using both radioactive and stable tracers have been performed in an effort to estimate turnover rates for various species and tissues (e.g., Libby et al. 1964; Mitchell et al. 1993; Stenhouse and Baxter 1979; Thompson 1953; Thompson and Ballou 1956; Tieszen et al. 1983). Smaller species with higher metabolic rates tend to have faster turnover rates than larger species with lower metabolic rates; similarly, metabolically-active tissues tend to have faster turnover rates than less-active tissues. Within species, young growing animals have higher turnover rates than do adults (Klepinger 1984). Diet quality has also been suggested to play a role in bone turnover rates (Parkington 1991); in particular, high protein diets may result in faster collagen turnover than low or adequate protein diets (Kennedy 1988).

Bone collagen has the slowest turnover rate among body tissues, and complete carbon turnover of adult human collagen is estimated to take on the order of 10 – 30 years (Stenhouse and Baxter 1979; Tuross and Fogel 1994; van der Merwe and Vogel 1978). What this means is that at any given time, the isotopic composition of bone collagen is a running average of current and past diet; the particular equation is governed by the rates at which old bone is resorbed, new bone is deposited, and the "old" fraction is recycled in the synthesis of new tissue. The bioapatite phase of bone also exchanges with the body reservoir through growth, modeling and remodeling during the individual's lifetime and thus, its composition,

like collagen's, will reflect an average diet accumulated over a long period of time.[25] Tuross and Fogel (1994) note that new dietary contributions will be incorporated into bone collagen more slowly as growth slows and this may be true of bioapatite as well. Due to differences in the rate of carbon assimilation during the life of an organism, the isotopic composition of bone probably reflects disproportionately the diet consumed during the animal's growth period.

Because different bones grow, model and remodel at different rates (Anderson 1968), one might anticipate variation in their chemical compositions under certain circumstances. For animals raised on controlled monotonous diets, there is no statistically significant variation in the stable carbon isotopic composition of collagen from different bones (DeNiro and Schoeninger 1983). Because of the way DeNiro and Schoeninger (1983) reported their data, it is not possible to say precisely what the inter-bone differences within individuals are; they do state that the variation was roughly 1 ‰ or less. Although Chisholm (1989) doesn't report what animal(s) or bones are involved, the isotopic compositions of different bones within individuals he analyzed differed by 0.2 ± 0.14 ‰; different parts of the same bones varied even less (0.1 ± 0.06 ‰).

Under conditions of a changing isotopic diet, collagen from bones with a more rapid turnover rate (e.g., vertebrae) might be expected to differ from those with a slower rate (e.g., femora). Historic Dutch whalers, documented in written records as having had significant seasonal variation in diet, were analyzed by Schoeninger (1989a). Comparisons of the isotopic composition of collagen from vertebrae and femora found they did not differ (Schwarcz and Schoeninger 1991).

One can also imagine that there might be differences in the relative degree of preservation from one element to another. Certainly, bones in the post-

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[25] In contrast to bone, the isotopic composition of enamel reflects dietary intake during the time of enamel formation; once that process is complete, enamel remains a closed system and no longer exchanges with the body reservoir.

depositional environment do vary in their potential exposure to, and interaction with, physical and chemical processes. Trabecular bone, for instance, has a greater surface area than cortical bone for chemical exchange. Although the trace element compositions of archaeological specimens have been shown to vary with the anatomical part analyzed (Grupe 1988; Lambert et al. 1982), there is no evidence for systematic variation in "collagen" $\delta^{13}C$ values across different bones (Schwarcz 1991). Ribs, which are predominantly trabecular bone, are the bones most frequently used for isotopic analysis; this presumably reflects both the frequency with which they are recovered and the limited loss of morphological information that results from their destruction (relative to that lost if femora or tibiae were used).

Potential Isotopic Variation with Consumption of Uniform Diets

There are two primary reasons why the isotopic composition of tissues may vary between individuals consuming the same diet: individual metabolic differences and differences in the particular isotopic composition of the foods consumed. Metabolic differences may arise because individuals vary in terms of their nutrient requirements, intake, and metabolism (Grummer 1975; Pond and Houpt 1978; Thirumurthi and Longenecker 1966; Tieszen 1991; Williams 1956). How they vary and how this variation affects the isotopic composition of their tissues is potentially influenced by several factors, including genetic predispositions, age, sex and health status.

After reviewing evidence for variation that may result from metabolic factors, I turn to a consideration of how environmental variation in the isotopic compositions of resources may contribute to isotopic variation in populations consuming the same diet. Environmental isotopic variation in the Eastern Woodlands occurs on two different scales, both of which are relevant: (1) there is geographic variation in the relative abundance of C_3 and C_4 plants across the region; and (2) the specific stable carbon isotopic compositions of the different resources

vary. Variation on these scales requires discrimination between diet, the actual foods consumed, and isotopic diet, the average isotopic composition of the foods consumed.

Genetic Variation

Biochemical individuality is a term used to denote the variation in animal physiology (e.g., nutrient requirements, enzyme levels, metabolic efficiency and tissue composition) that results from an individual's unique genetic makeup (Thirumurthi and Longenecker 1966). This genetic component to animal metabolism is generally ignored, and this is particularly problematic for controlled-feeding studies. Experimental research, which often relies on genetically-inbred stock (Cox 1966; Williams 1956) and which often emphasizes *average* responses at the expense of *variation* in responses, tends to minimize variation due to biochemical individuality (Thirumurthi and Longenecker 1966). Indeed, one reason why laboratory studies typically document less variation in tissue chemistry than field studies (Cormie and Schwarcz 1994; Hobson and Schwarcz 1986) may lie in the genetic composition of the populations studied. Natural populations probably are characterized by greater genetic diversity than highly inbred laboratory ones. The other, more obvious, reason for that observation is that field populations may exhibit unknown and, hence, uncontrolled dietary variation.

Among field and laboratory studies, the amount of isotopic variation exhibited by animal populations is unevenly reported. Variation across factors like sex and age is not always examined, particularly in field populations. Table 2 provides a sense of the variation in bone collagen $\delta^{13}C$ values documented for laboratory and field studies; where multiple populations were studied, animals with the largest and smallest standard deviations are listed to show the range of variation reported. All of the laboratory and all but one of the wild populations have standard deviations less than 1.0 ‰, suggesting that any genetic contribution to metabolic variation in $\delta^{13}C$ values among individuals is likely small.

Table 2. Range of variation in collagen $\delta^{13}C$ values of animal populations as documented by several laboratory and field studies.

Animal	n	SD (‰)	Reference
Laboratory Studies:			
mink[1]	15	0.2	DeNiro and Schoeninger 1983
rat[1]	4-10	0.08	Ambrose and Norr 1993
rat[1]	4-10	0.19	Ambrose and Norr 1993
mouse	4	0.16	Tieszen and Fagre 1993b
mouse	4	0.83	Tieszen and Fagre 1993b
pig	5	0.13	this study
pig	5	0.40	this study
Field Studies:			
zebra	3	0.2	Sillen 1988
bushpig	8	0.9	Sillen 1988
zebra	12	0.9	Ambrose and DeNiro 1989
bushpig	7	3.4	Ambrose and DeNiro 1989
mule deer[1]	55	0.5	Hobson and Schwarcz 1986
vole	22	0.6	Hobson and Schwarcz 1986
bison[1]	19	0.2	Tieszen 1994
elephant[1]	65	0.18	Tieszen et al. 1989

[1] No correlation of $\delta^{13}C$ with age and/or no difference in $\delta^{13}C$ between sexes

The pig study, as described in Appendix C, took care to distribute littermates across four different diets; the pigs are all the same age and same sex (female). Table 3 shows how four litter outcome groups rank from 1 (most enriched) to 4 (least enriched) for each diet; a mixed litter group was not included. Although some patterning in this small sample is suggested, it is not statistically significant (Kendall's W = .375; p = .212); the standard error associated with the replicate

determinations, ranked from 1 (smallest) to 4 (largest), does not differ statistically, either (W = .625; p = .058). Since the sample preparations were performed in a random order, that isotopic determinations for bones from the members of litter outcome group 77 consistently have the greatest precision may indicate less variation in the composition of the organic fraction in those individuals. At any rate, because this is a small sample, it is not possible to tease out the role of genetic factors in varying tissue chemistry; to do so requires a larger sample of individuals than currently available.

Table 3. Stable carbon isotope determinations and associated standard errors of the litter outcome groups (77, 79, 80, 81) ranked for each experimental diet.

	δ^{13}C Rank[1]				SE Rank[2]			
Diet	77	79	80	81	77	79	80	81
1	2	1	4	3	1	4	3	2
2	2	1	3	4	1	2	4	3
3	2	3	4	1	1	4	3	2
4	3	1	2	4	1	2	3	4

[1] Ranked from 1 (most enriched) to 4 (least enriched)
[2] Ranked from 1 (smallest error) to 4 (greatest error)

Age

Cross-sectional data from several field studies do not indicate any age-based physiological effect on carbon isotope metabolism. In an analysis of bone collagen obtained from 65 elephants that died during a five year period in Tsavo National Park, Kenya, Tieszen et al. (1989) found no relationship between δ^{13}C and animal age, which ranged from 1 – 60 years at death; they found this particularly surprising, given historically-documented changes in the local vegetation. Similarly, in an analysis of bone collagen from 55 mule deer from north central Colorado, Hobson and Schwarcz (1986) found no relationship between δ^{13}C and animal age. Finally, Minagawa's (1992) cross-sectional study of the isotopic

composition of contemporary Japanese hair found no evidence for a metabolic age effect on $\delta^{13}C$ values. The $\delta^{13}C$ values of "collagen" from archaeological human populations believed to have consumed relatively uniform diets do not vary with age at death, either (Lovell et al. 1986; Schurr 1989). Taken together, these cross-sectional data suggest that when age-related variation in $\delta^{13}C$ values occurs in archaeological populations, dietary (behavioral), rather than metabolic, differences are being reflected.

Sex

Neither field nor laboratory analyses comparing the stable carbon isotope composition of collagen in males and females consuming the same diet have identified sex-based metabolic differences. DeNiro and Schoeninger (1983) found no significant difference at $\alpha = .05$ in the isotopic composition of bone collagen between eight female and seven male mink raised on controlled diets. In an analysis of bone collagen obtained from 65 elephants at Tsavo National Park, Kenya, Tieszen et al. (1989) found no statistical difference in $\delta^{13}C$ values between the sexes, while Hobson and Schwarcz (1986) found no difference between males and females from 55 mule deer from north central Colorado. Similarly, a study of $\delta^{13}C$ values of contemporary human hair found no difference between males and females in Japan (Minagawa 1992). Like the modern cases, in archaeological human skeletal populations believed to have consumed a uniform diet, there is no difference in the $\delta^{13}C$ values of males and females (e.g., Boutton et al. 1991; Broida 1983; Conard 1988; Lovell et al. 1986; Schurr 1989; White and Schwarcz 1989). Thus, with the evidence accumulated thus far, it appears that the occurrence of statistically different $\delta^{13}C$ values between males and females in archaeological skeletal populations must be due to behavioral (i.e., dietary), and not metabolic, differences.

Disease

Illness which disrupts an individual's metabolic processes could potentially affect the isotopic composition of their tissues. Whether or not such

diseases actually do affect $\delta^{13}C$ values is not known. Although Lyon and Baxter (1978) found no difference in the isotopic composition of cancerous and healthy contemporary human tissues, their analysis did not compare the two kinds of tissues in single individuals, but instead looked at their distributions within 80 total samples from an unknown number of individuals. Still, it is conceivable that conditions involving, for example, intestinal malabsorption or pancreatic dysfunction, might alter the isotopic composition of tissues in a sick individual relative to those in a healthy individual on the same diet.

Clinical research using ^{13}C-labeled substrates to diagnose various metabolic conditions (e.g., Klein and Klein 1985; Schoeller et al. 1977, 1980, 1981; Solomons et al. 1977) is not designed to provide information regarding isotopic discrimination during metabolism, nor do the results reveal the long-term effects of these conditions on the isotopic composition of tissues. One example, however, that might lend support to the notion that at least some physiological conditions might produce different isotope ratios in body tissues is discussed by Schoeller et al. (1980). Compared with results in normal infants tested under the same conditions, infants with cystic fibrosis, who have abnormal fat oxidation because of impaired pancreatic function, showed significantly greater amounts of fat in their feces and lower concentrations of $^{13}CO_2$ in breath tests following administration of an isotopically-labeled formula. The isotopic contribution of dietary fat (which is significantly correlated with both bioapatite and collagen $\delta^{13}C$ values [Tieszen and Fagre 1993b]) to the body carbon pool must be significantly reduced in the cystic fibrosis patients relative to normal subjects. Since dietary fats are routinely depleted in ^{13}C relative to the bulk diet, the bioapatite and, to a lesser degree, collagen of individuals who cannot oxidize fat should have more positive $\delta^{13}C$ values than normal individuals.

The extent to which the stresses that produce skeletal pathologic conditions also influence the incorporation of $\delta^{13}C$ into bodily tissues is unknown,

but because indicators of physiological stress are frequently found in archaeological skeletal populations, this question is worth considering (cf. Schwarcz and Schoeninger 1991). The skeletal pathologies that are often found (e.g., Harris lines, linear enamel hypoplasias, porotic hyperostoses) are not attributable to specific physiological stresses. In some cases they may be associated with nutritional deficiency and, in others, disease. Because turnover rates are on the order of 10 to 30 years, these conditions would need to be either chronic or severe to be detectable in stable carbon isotope ratios of bone. Comparing $\delta^{13}C$ values of remodeled bone associated with periosteal lesions (skeletal responses to nonspecific infection or injury) with healthy bone, on the other hand, may provide temporally-delimited insights into the effects of disease on carbon metabolism.

Environmental Variation

The relative abundance of C_4 grasses in eastern North America is highly correlated ($r = .972$) with July minimum temperatures (Teeri and Stowe 1976). Using the equation that describes that relationship, the percentage of C_4 grass species was estimated using historic temperature data from meteorological stations in and around the study area (Appendix E). Figure 42 maps the macroscale distribution of C_4 grasses among grass taxa across the study area. Because it ignores potentially important variation in the local environment (e.g., soil types, amount of shade) and because it does not estimate the total C_4 abundance, just grasses, the map is an obvious simplification; it does serve to illustrate the point, however, that there may be considerable variation in the isotopic composition of the vegetation across the study area. Note, too, that the distribution of C_4 plants almost certainly varied temporally as climatic conditions across the area changed.

Since most of the native C_4 taxa are grasses, that they occur in different abundances across the Ohio Valley may not be too significant in terms of human exploitation of plants. As far as we know, with the exception of maize, C_4 plants did

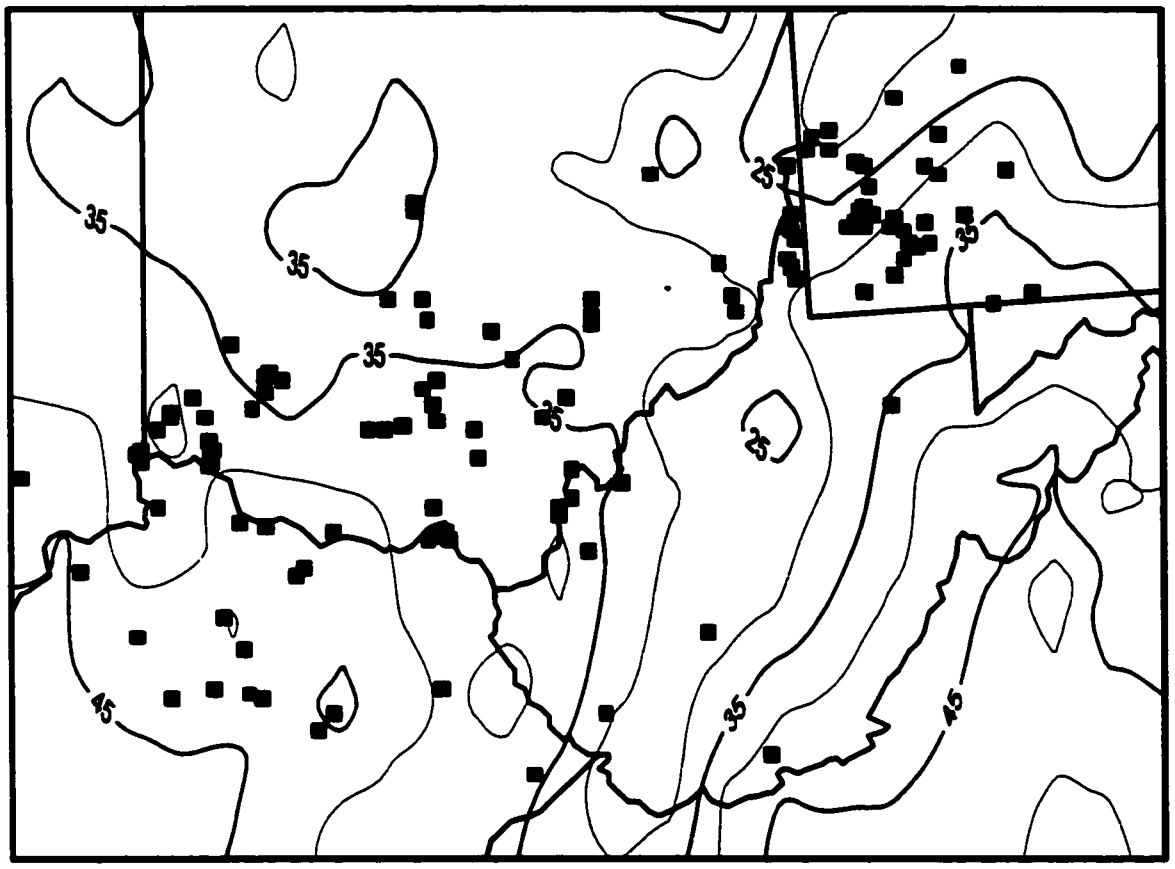


Figure 42. **Relative abundance of C_4 taxa among grasses.** Estimates based on July minimum temperature data from historic meteorological stations. Symbols indicate archaeological locales listed in Appendix A.

not directly comprise a significant portion of prehistoric human diets in the region. Where this variation in the relative proportion of C_4 taxa might be important, though, is in the herbivores that might have eaten those C_4 resources and then were subsequently eaten by people. From this perspective, cultivated maize must also be considered part of the environmental isotopic background that contributed to the isotopic diet of the local fauna.

Stable carbon isotope analyses of wild fauna from the Eastern Woodlands are generally in line with expectations for animals living in a C_3-dominated environment (Table 4). Among the modern specimens, the white-tailed

Table 4. Stable carbon isotope analyses of collagen from fauna in and around the study area.

Taxon	Location	n	$\delta^{13}C \pm SD$ (‰)	Reference
Modern Specimens[1]:				
deer	West Virginia	3	-17.7 ± 1.3	Cormie and Schwarcz 1994
deer	Ohio	2	-23.8 ± 1.7	Cormie and Schwarcz 1994
deer	Ohio[2]	1	-12.4	Cormie and Schwarcz 1994
deer	Michigan	13	-19.3 ± 1.8	Cormie and Schwarcz 1994
Archaeological Specimens:				
duck	SE Wisconsin	1	-24.3	Bender et al. 1981
goose	S Ontario	2	-21.0 ± 0.5	Katzenberg 1989
turkey	SE Wisconsin	1	-19.4	Bender et al. 1981
turkey	SW Ohio	10	-21.5 ± 1.4	Conard 1988
turkey	S Ontario	1	-19.2	Katzenberg 1989
deer	SE Wisconsin	1	-21.1	Bender et al. 1981
deer	SW Illinois	1	-21.4	Bender et al. 1981
deer	SW Ohio	4	-21.0 ± 0.4	Conard 1988
deer	S Ontario	7	-22.2 ± 0.3	Katzenberg 1989
deer	SE Missouri	2	-20.1 ± 0.2	Boutton et al. 1991
deer	N West Virginia	?	-22.21	Farrow 1986
elk	SW Ohio	1	-22.1	Conard 1988
squirrel	SW Ohio	1	-19.3	Conard 1988
raccoon	SW Ohio	4	-19.6 ± 2.4	Conard 1988
raccoon	S Ontario	2	-22.8 ± 2.4	Katzenberg 1989
bear	S Ontario	5	-20.8 ± 0.9	Katzenberg 1989
dog	S Ontario	8	-11.1 ± 0.9	Katzenberg 1989
woodchuck	S Ontario	2	-24.5 ± 0.6	Katzenberg 1989
beaver	S Ontario	5	-22.6 ± 0.6	Katzenberg 1989
walleye	S Ontario	1	-17.8	Katzenberg 1989
sucker	S Ontario	1	-23.1	Katzenberg 1989
pickeral	S Ontario	1	-20.8	Katzenberg 1989

[1] As per Cormie and Schwarcz (1994), 0.6 ‰ has been subtracted from each $\delta^{13}C$ value of modern specimens to compensate for contribution of carbonate to whole bone powder used in analysis. The $\delta^{13}C$ value of each modern specimen has been increased by 1.5 ‰ to compensate for atmospheric depletion.

[2] Deer fed corn in captivity

deer samples from West Virginia and Michigan are slightly-enriched;[26] since these browsers rarely eat grass, it is believed they probably had access to maize fields (Cormie and Schwarcz 1994). The archaeological specimens, all from Late Prehistoric contexts with evidence for maize farming, provide uneven evidence for consumption of C_4 resources. Although archaeological deer specimens show no ^{13}C enrichment, a few specimens of turkey, raccoon, squirrel and bear had consumed small amounts of C_4 resources, which could have included maize. In contrast, dog "collagen" is consistently and highly enriched, indicating they scavenged, or were fed, a maize-based diet.

The sample of isotopically-analyzed faunal remains is small. It will be interesting to see how geographic and temporal patterning in isotopic enrichment within and between taxa appears as the sample size increases in the future. As it now stands, consumption of the wild fauna would probably have resulted in only minor ^{13}C enrichment of human tissues, as the flesh of these animals was only about 1 – 2 ‰ more enriched than the plants they ate. Variation among different groups of human consumers eating the same faunal diet could arise depending upon how the consumption of the fauna was distributed (e.g., did some populations concentrate on exploitation of relatively enriched individuals, as might be expected with garden hunting strategies, while others relied on fauna that avoided garden situations?).

Although eating the wild fauna would have caused only minor variation in the isotopic composition of human tissues, eating dog meat[27] with

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[26] Because fossil fuel combustion during the historic era has released depleted $^{13}CO_2$ into the atmosphere, the modern atmospheric $\delta^{13}C$ value is depleted by about 1.5 ‰ relative to prehistoric values (Tieszen and Fagre 1993a). Thus, to be comparable to archaeological specimens, the $\delta^{13}C$ values of modern samples should be adjusted positively by that amount.

[27] Recall from Figure 27 that animal flesh is depleted relative to bone collagen by roughly 3 – 4 ‰, and that animal fat is depleted even more (by 7 – 10 ‰ relative to collagen).

estimated $\delta^{13}C$ values of roughly -15 ‰, could have had a significant impact on them. That domestic dogs were at times exploited prehistorically as a food resource is fairly clear (Snyder 1989 and references therein) and the Ohio Valley is no exception. Most of the archaeological dog remains there are disarticulated, they come from midden contexts, and they frequently show cutmarks (inferred to reflect butchering) or other modifications. It is important to note that, although the "collagen" from eight dogs at the Kelly-Campbell site in southern Ontario showed little isotopic variation (Katzenberg 1989), there is no reason to believe that the $\delta^{13}C$ composition of dogs across the study area will be uniform. The dogs should vary isotopically at least as much as their human providers did and thus, they should have had a variable input into the isotopic diets of the people who ate them.

Even as the specific $\delta^{13}C$ values for faunal resources can be expected to vary with the proportion of C_3 and C_4 resources they consume, the specific $\delta^{13}C$ values for the plants vary, also. Environmental and ecological factors such as temperature, precipitation, humidity, irradiance, altitude and canopy conditions affect the way both C_3 and C_4 plants discriminate against ^{13}C during photosynthesis (Macdowall and Lowdon 1989; Medina and Minchin 1980; O'Leary 1981; Stuiver and Braziunas 1987; Tieszen 1991, 1994; van der Merwe and Medina 1991). There appears, as well, to be a genetic component that determines how different plants will respond isotopically to environmental stresses. Variation in all of these factors may cause individual plant $\delta^{13}C$ values to differ by as much as $2 - 6$ ‰, depending upon the particular situation; plants grown in the laboratory under extreme experimental conditions have shown even greater deviation from "average" values (Tieszen 1991).

Because the isotopic biochemical composition of plants differs (as it does in animals), and because different plant tissues are composed of different amounts of these biochemicals, different plant tissues may have different $\delta^{13}C$ values (Tieszen 1994). Thus, the isotopic compositions of leaf and stem tissues may

differ from those of the root and the seeds. Even the isotopic compositions of seeds from a single plant may vary depending upon their relative size and where on the plant they are located (Tieszen and Fagre 1993a). Consequently, what particular plant tissues are consumed will determine the isotopic contribution made by that plant to the consumer. Digestability of consumed tissues may also play an important role; for example, fiber apparently makes no isotopic contribution to the consumer's tissues as it travels through the digestive system (Tieszen and Fagre 1993b). Since the digestibility and bioavailability of nutrients may be altered by resource processing techniques (Brenton 2000), they may also be sources of isotopic variation in populations consuming the same diet.

Variation in the stable carbon isotopic composition of maize is of particular importance to archaeologists studying dietary change associated with the spread of maize farming in the New World. Some (Buikstra et al. 1988; Conard 1988; Schoeninger and Schurr 1994; Wagner 1987) have speculated, based on reported differences in the isotopic composition of modern and archaeological maize specimens, that the high level of ^{13}C enrichment documented in the bone collagen of maize farmers from some parts of the Eastern Woodlands might be due to their consumption of a relatively enriched type of maize, specifically that type known as Eastern Eight-Row or Northern Flint. Tieszen and Fagre (1993a) have analyzed maize from modern and archaeological sources and compared their results with previously published $\delta^{13}C$ values on archaeological maize kernels. Their and others' data are presented in Table 5.

Tieszen and Fagre (1993a) concluded that (1) there are statistically significant differences in isotopic composition among the different modern collections that appears to reflect geographic variation in atmospheric $^{13}CO_2$ concentrations, (2) different types (e.g., flint, dent, flour) of maize do not differ isotopically, (3) carbonization does not significantly alter the $\delta^{13}C$ values of kernels, and (4) when adjustments are made for atmospheric $^{13}CO_2$ depletion, the $\delta^{13}C$ values

Table 5. Comparison of $\delta^{13}C$ values for uncharred modern and charred archaeological maize specimens.

Collection Source	Mean ± 1 SD (‰)	Adjusted[1] (‰)	n	Reference
Modern Specimens:				
Pioneer Hi-Bred	-11.2 ± 0.21	-9.7 ± 0.21	50	Tieszen and Fagre 1993a
CIMMY	-11.00 ± 0.53	-9.5 ± 0.53	59	Tieszen and Fagre 1993a
Goodman	-10.7 ± 0.28	-9.2 ± 0.28	193	Tieszen and Fagre 1993a
Miracle Food Mart	-10.5 ± 0.1	-9.0 ± 0.1	5	Schwarcz et al. 1985
Archaeological Specimens:				
Chile	-9.66 ± 0.44		5	Tieszen and Fagre 1993a
Ontario	-9.06 ± 0.36		8	Schwarcz et al. 1985
Crow Creek, SD	-10.6 ± 0.5		5	Boutton et al. 1991
Aztalan, Wisconsin	-11.1		--	Bender 1968
Aztalan, Wisconsin	-11.3		--	Bender et al. 1981
Baum, Ohio[2]	-8.6		--	Schurr and Schoeninger 1995
Gartner, Ohio[2]	-8.7 ± 0.6		--	Schurr and Schoeninger 1995
Incinerator, Ohio[2]	-8.4 ± 0.2		--	Schurr and Schoeninger 1995
Feurt, Ohio[2]	-8.4		--	Schurr and Schoeninger 1995
Angel, Indiana[2]	-8.8		--	Schurr and Schoeninger 1995

[1] Modern specimens adjusted for historic era atmospheric $^{13}CO_2$ depletion by adding 1.5 ‰ to the measured value

[2] $\delta^{13}C$ values estimated from their Figure 2

of their archaeological maize kernels do not differ from their modern ones. Although the Ohio Valley archaeological kernels still appear to be enriched, most samples overlap with modern $\delta^{13}C$ values at two standard deviations. Certainly, comparison of Figure 18 (the relative frequency of 8-row maize cobs in the Ohio Valley) with Figure 25 (the mean $\delta^{13}C$ values for Ohio Valley populations) suggests, if anything, a negative correlation between the frequency of Eastern Eight-Row maize and isotopic enrichment. If nothing else is clear, there is certainly considerable variation in the isotopic composition of maize; analysis of a larger sample is necessary to determine if and how the isotopic composition of maize was structured by environmental parameters.

Although a potentially significant amount of variation in the environmental isotopic background exists, it was probably structured both geographically and temporally. Thus, as these environmental factors become better delineated, greater precision estimating the direction and magnitude of their effects on plant $\delta^{13}C$ values will be possible, and valuable insight into how this variation was structured will be obtained. It is important to remember that, in spite of this highly variable isotopic background, most animal populations display amazingly low variation in their bone collagen, generally less than 1 ‰ and often on the order of 0.2 ‰. Apparently the slow-turnover rate of collagen results in an average $\delta^{13}C$ value that integrates both temporal and environmental variation in the isotopic diet over the long term.

Isotopic Variation Associated with Consumption of Different Diets

Many animal species display dietary differences with age, sex, social status, geographic location and/or season. Humans are no exception. Below, I describe briefly the nature of stable carbon isotopic variation associated with dietary differences among modern and prehistoric groups of people. This is not an exhaustive consideration of all possible causes for dietary variation; the point here is to show how archaeologists have used the inter- and intra-populational patterns of isotopic variation to discern the reasons for that dietary variation.

Geography

Geographic variation in dietary resources and their isotopic compositions has been shown to account for interpopulational differences in $\delta^{13}C$ values of hair and tissues from contemporary peoples (Gaffney et al. 1978; Nakamura et al. 1982). Archaeologists have used this observation, that the tissues of people from different places may have different isotopic compositions, to explain some aspects of variation in archaeological skeletal populations.

If diet varies geographically, then individuals raised in a population different from the one with which they are buried likely consumed a different diet over their lifetime and they may have $\delta^{13}C$ values that differ significantly from those of the remainder of the burial population. There are several archaeological examples of this sort of interpretation (e.g., Buikstra 1991; Greenlee 1990; Hobson and Collier 1984; Schurr 1989, 1992; Verano and DeNiro 1993; Walker and DeNiro 1986), and the argument is made stronger when the individuals were treated at death differently from the rest of the population. It is important to keep in mind that, for this approach to be successful, foreigners must come from a population with an isotopically distinct diet and they cannot have been part of the local group for so long that bone turnover has eliminated any isotopic differences. Consequently, there are cases where known foreigners were found not to differ isotopically from the rest of the population (Greenlee 1998).

Another situation where geographic variation in resource use is used to account for isotopic variation in archaeological skeletal populations has to do with mobility among different ecozones. If populations moved among different ecozones characterized by isotopically different resources, then the isotopic composition of their tissues should differ from sedentary populations who used resources from only a single ecozone. Probably the most frequent application of this line of reasoning involves distinguishing the use of coastal versus inland ecozones by different groups (Hobson and Collier 1984; Lee-Thorp et al. 1989; Parkington 1991; Sealy and van der Merwe 1985, 1986; Walker and DeNiro 1986).

A third approach turns the geographic hypothesis for isotopic variation on its ear. Rather than relying on the observation that populations from different geographic areas have different isotopic diets, in this approach, variation in local environmental conditions is used to account for geographic patterns in diet. Variation in the timing or degree of dietary reliance on maize between populations in different regions is explained as a function of the relevant circumstances (e.g.,

richness and productivity of the local environments) (Greenlee 1990, 1998; Greenlee and Dunnell 1990; Lynott et al. 1986; Schurr and Schoeninger 1995).

Sex and Age

In the absence of evidence for sex-based metabolic differences, whenever males and females in a population display different $\delta^{13}C$ values, it is believed that these values reflect different diets (Bender et al. 1981; Reed 1994; Sealy and van der Merwe 1988; van der Merwe and Vogel 1978; Wilson 1997). When they do occur, dietary differences between males and females are often differences in dietary variance rather than differences in mean isotopic diet.

Differences in the isotopic composition of infants and children (as compared with adults) that reflect nursing and weaning diets are prime examples of age-based dietary variation. At birth and while nursing, the tissues of baby animals reflect generally the isotopic diet of their mothers, but they tend to be slightly depleted in ^{13}C relative to their mothers' tissues (Mitchell et al. 1993; Tieszen and Fagre 1993b).[28] If the mothers' isotopic diets change, the isotopic composition of milk changes as well (how closely is apparently determined by what proportion of the stored body carbon pool is used in milk production [Mitchell et al. 1993]).

As the weaning process begins, the young animals begin to incorporate carbon from their solid diet and, as solid foods replace milk, their tissues eventually equilibrate with that diet. In young, growing animals this equilibration occurs relatively rapidly and there is no long-term isotopic memory effect from the maternal diet (Ambrose and Norr 1993). In archaeological populations of eastern North America, $\delta^{13}C$ values of "collagen" from infants and

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[28] For stable nitrogen isotopes, the offspring is enriched by about 3 ‰; nitrogen isotopes record a trophic level effect, as the infants "feed" on their mothers, that is not apparent in carbon isotopes (Fogel et al. 1989; Katzenberg 1993; Schurr 1997; Tuross and Fogel 1994).

children that are higher than in adults have been interpreted to reflect a maize-derived weaning diet (Katzenberg 1993; Katzenberg et al. 1993).

Status

Status differences are frequently invoked as an explanation for dietary variation. Although some argue that differences in burial treatment reflect status in life (e.g., Balter 1995; Binford 1971; O'Shea 1984; Peebles 1971), this is an untestable inference made with little empirical basis. In any case, when individuals accorded elaborate mortuary treatment have isotopic values that differ from the rest of the community, the "elites" are argued to have had a different diet from the "commoners" (e.g., Bender et al. 1981; Reed 1994; Rose et al. 1991; White and Schwarcz 1989). The issue then becomes one of determining what resources the "elites" had "access" to that the "commoners" did not.

Community Structure

How people distribute themselves, both through the annual seasonal cycle and across the landscape, is influenced by the availability and productivity of exploitable resources and, in turn, influences the nature of their subsistence systems. Thus, dietary variation might well be explicable, in part, by the structure of the settlement system involved. Indeed, settlement variation has been used to account for some aspects of the stable carbon isotopic record in human populations (Greenlee 1990; Schurr and Schoeninger 1995).

CONCLUSIONS

There are demonstrated relationships between the isotopic composition of an animal's diet and the composition of its tissues. Bone collagen is one tissue that reflects the isotopic composition of the diet and that is typically well-preserved in archaeological circumstances. However, it is clear that we cannot now, nor may we ever be able to, say with confidence that a certain collagen isotope ratio

corresponds to a diet of a particular composition. In situations where the range of resources is isotopically limited, an animal's collagen may reflect the consumption of isotopically rare resources. Thus, in the interior Eastern Woodlands, the isotopic composition of human bone collagen will record the relative consumption of maize, a C_4 resource in a predominantly C_3 environment. This is precisely the kind of information required by this research problem.

When reported, the standard deviations for collagen samples from groups of animals raised on controlled diets are consistently less than 1 ‰ (Table 2). Surprisingly, despite the many sources of environmental variation in the isotopic composition of plants, there is generally little isotopic variation within wild animal populations eating uncontrolled, but presumably similar, diets. Indeed, of wild animal populations studied, collagen from most have standard deviations below 1 ‰ as well. From this, we might estimate conservatively that collagen isotope ratios differing by 2 ‰ or more indicate behavioral variation, i.e., the consumption of significantly different diets.

The 2 ‰ estimate for significant dietary differences is based on data generated using modern animal sources. Postdepositional alterations can influence the isotopic integrity of "collagen" acquired from archaeological bones, making evaluation of collagen extracts a necessary step in archaeological isotopic analyses. Even though archaeological "collagen" tends to be relatively well-preserved in most bones from Ohio Valley locales, assessments of preservation are required to demonstrate that the isotopic signature of "collagen" from archaeological human skeletal remains reflects premortem dietary values. Once the integrity of archaeological human bone "collagen" samples is established, there can be little doubt that subsequent measurements of stable carbon isotopic composition reflect the relative consumption of maize by prehistoric people in the Ohio Valley.

CHAPTER FIVE: ISOTOPIC DIET AMONG OHIO VALLEY POPULATIONS

Chapter Two shows that there are some gaps in the existing database that prevent a clear understanding of the timing and tempo of dietary change associated with the spread of maize farming. In particular, the critical time period for understanding this change, the Late Woodland period (A.D. 400 - 1000), is poorly represented in the middle and upper Ohio Valley. The regional distribution of samples is a second weakness, with Upper Valley contexts being significantly underrepresented. Consequently, considerable effort was expended here toward identifying and obtaining Late Woodland skeletal samples and increasing the number of samples from the upper Ohio Valley (Figure 43).

Relevant skeletal samples were identified by searching the archaeological literature of the middle and upper Ohio Valley and by contacting archaeologists active in the study area. Because it appeared to be the critical time of dietary change, particular effort was placed on identifying and locating Late Woodland samples. Radiocarbon determinations were obtained for several skeletal populations that I believed (based on associated artifacts, depositional contexts and/or attributions by other archaeologists) were potentially Late Woodland in age; some of these were determined to be either earlier (Ufferman, C. L. Lewis and Chilton) or later (Childers, Enos Holmes, and O. C. Voss) in time. Late Prehistoric samples from Middle Valley skeletal populations were selected to improve the geographic and temporal distribution of the existing isotopic database.

Other criteria important to the selection of samples included the availability of skeletal materials for destructive analysis, the elements represented (because of their relatively greater resistance to post-depositional alteration, only long bones were included in this research), the condition of the bone (samples with glue, ink, and/or preservatives were avoided as much as possible; when unavoidable, those substances were carefully removed during sample preparation), the age-at-

death of the individual (only adults were included in this research), the availability of complementary subsistence and settlement data, and the size of the sample population (when 15 individuals or fewer were available, a sample was taken from each individual; when more than 15 individuals were available, samples were selected randomly until at least 15 [up to 25 when possible] samples were obtained).

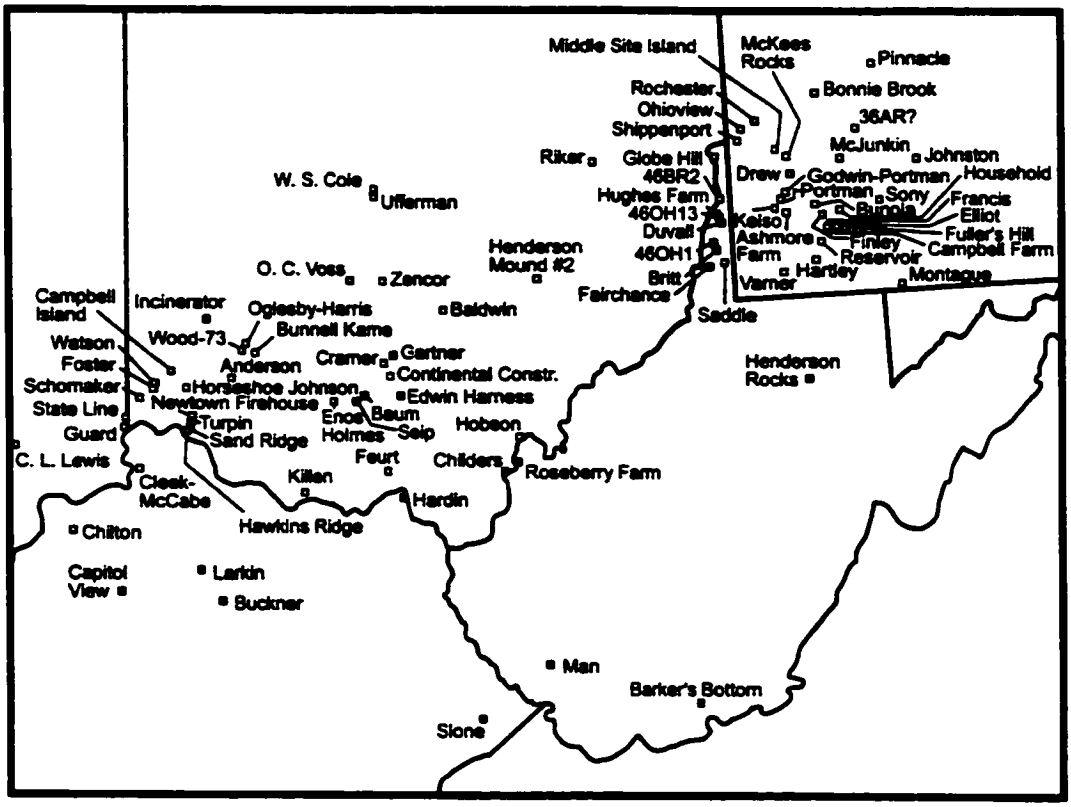


Figure 43. **Map of locales with newly-generated and previously-acquired stable carbon isotope data.** Symbols with white fill indicate locales with newly-generated data, with black fill indicate locales with previously-acquired data, and with gray fill indicate locales with both. Six locales (Rinehart, Proctor, Felix, King, A. M. Byer and Barn) are not mapped because no information as to their locations was available.

Bone samples from all Upper Valley and three Middle Valley locales were selected in accordance with the above criteria by Dr. Paul W. Sciulli, Ohio State University. These samples were presented for chemical analysis without documentation (i.e., a blind test). Upon completion of the analyses, relevant

information (e.g., site name/number, time period, sex and age-at-death) was revealed. As of this writing, however, little is known about several of these locales (e.g., exact location, age of occupation, distribution of burials, accompanying subsistence data). No radiocarbon determinations were obtained on Upper Valley bone samples of questionable age as part of this research because which samples were problematic was not known until after all of the analyses were completed.

Figure 44 shows the temporal distribution (tabulated for 200-year intervals) of isotopically-analyzed skeletal samples, comparing previously-collected data with the data generated for this research. Although this research increases the number of Late Woodland samples significantly, the number of samples representing that part of the sequence is still fewer than desired. This reflects, in part, the scarcity of appropriately-aged materials due to lower relative archaeological visibility of Late Woodland burial deposits and less overall interest on the part of archaeologists in the record of that time period.

Figure 45 shows the distribution of individuals between the Upper and Middle Valleys within the existing database, within my sample, and in the total combined sample. Although individuals from Middle Valley locales continue to dominate the total sample, the addition of data generated by this research more than doubles the proportion of individuals from Upper Valley locales. The then-extant Upper Valley samples were restricted to the panhandle and northeastern part of West Virginia; my new Upper Valley samples are dispersed throughout southwestern Pennsylvania (Figure 43) and thus increase greatly the area represented by the dataset.

This research not only more than doubles the number of individuals with stable carbon isotope data from the study region, but it also does so with specific goals in mind. After an assessment of "collagen" sample integrity, stable carbon isotope data from 251 archaeological human skeletons from 69 localities in

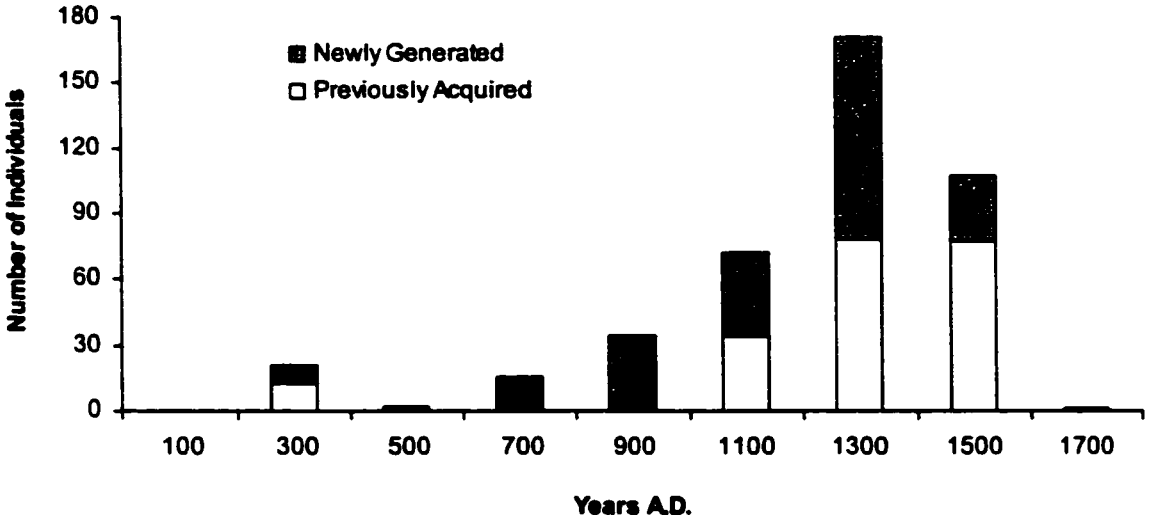


Figure 44. **Temporal distribution of previously-acquired and newly-generated "collagen" samples.** Samples are divided into 200-year intervals. Note that without the new samples there is no basis for examining the manner and timing of maize agriculture's spread in the region.

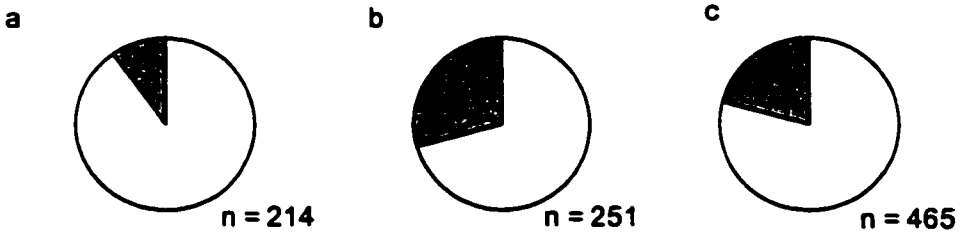


Figure 45. **Relative representation of individuals from Middle (white) and Upper (gray) Valley locales.** (a) previously-acquired (b) newly-generated, and (c) total sample.

the middle and upper Ohio River valleys (Appendix F) are presented. For testing hypotheses about the spread of maize farming, I combine the previously-acquired and my newly-generated data sets to obtain an unusually large sample of isotope

data. Although methods have improved over time, the fundamental approach is constant across these data and warrants their merger.

BONE PRESERVATION

Controlled-feeding studies indicate that, all other things being equal, the bioapatite fraction of bone best reflects the bulk isotopic diet. All other things are not equal, however. Archaeological research needs to take into account bone diagenesis. In temperate environments at least, collagen appears to be more stable than bioapatite. As shown in the previous chapter, "collagen" extracted from Ohio Valley skeletal materials tends to be reasonably well-preserved. Consequently, I have used "collagen" here. It is also the material used in all earlier isotopic studies in the region.

Visual and chemical examination of the histological microstructure for a small sample of the specimens available for this analysis showed significant alterations to the mineral phase of bone (Greenlee 1996). Comparing modern (Figure 46a) with archaeological bone samples (Figures 46b – d) shows the latter as having diagenetically altered areas, which appear in backscattered electron (BSE) images as rounded, irregularly-shaped "blobs" with hypermineralized borders and variable interior density. These kinds of alterations, known as destructive foci, are characteristic of mineral dissolution associated with microorganismic activities, followed by remineralization (Bell 1990; Garland 1987, 1989; Hackett 1981; Hanson and Buikstra 1987; Marchiafava et al. 1974). Trace element analysis of these altered areas suggests that remineralization incorporated ions from both dissolved bone mineral and the soil solution (Greenlee 1996). Thus, there is a danger that biogenic carbonates in the mineral matrix may have been replaced by carbonates from the surrounding environment.

Extraction protocols used by archaeologists to obtain $\delta^{13}C$ values for carbonate in bone bioapatite rely on the observation that secondary carbonates tend

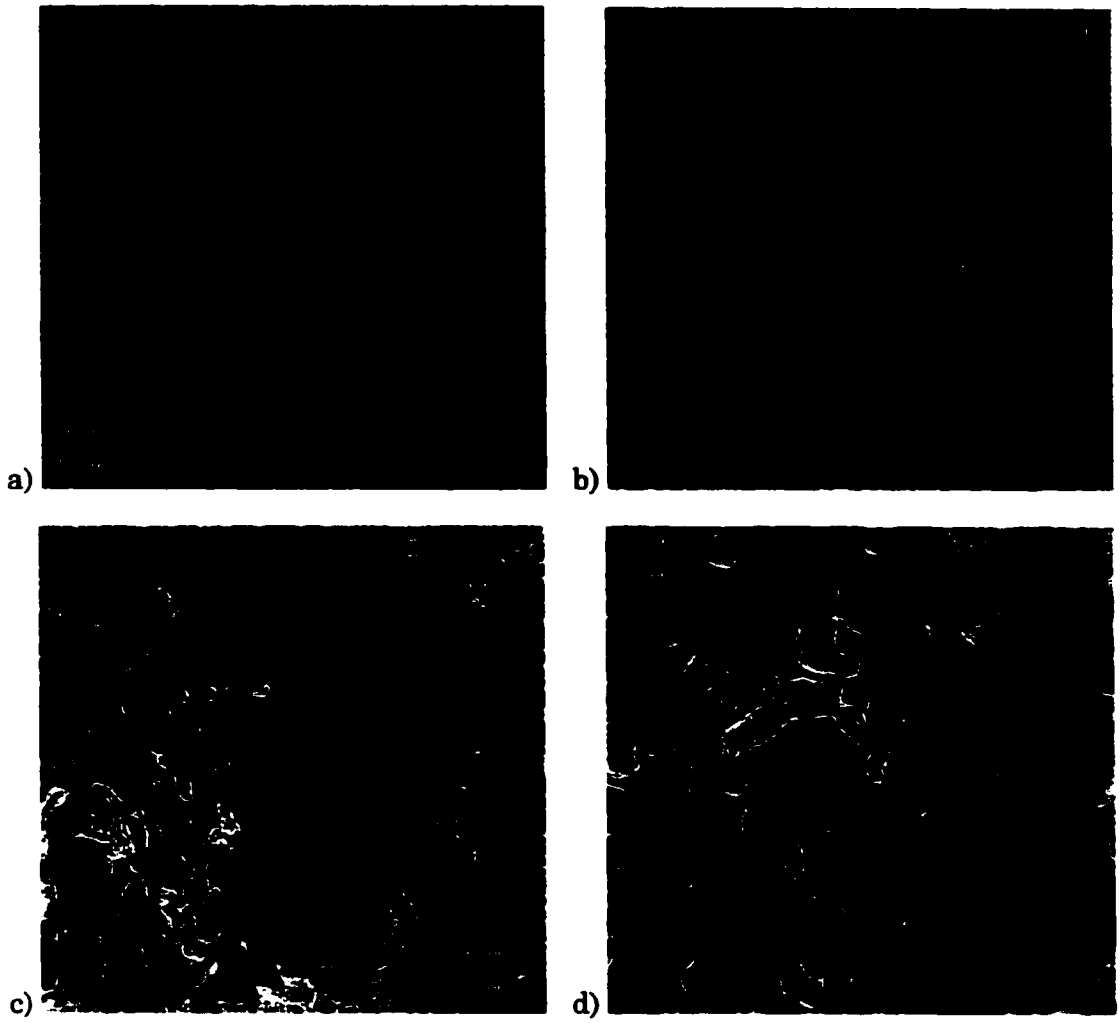


Figure 46. BSE images showing histological structure in (a) modern and (b-d) archaeological human bones. Destructive foci are particularly clear as white-rimmed "blobs" in images (c) and (d). Image (b) shows more structurally-intact bone mineral than does (c) or (d). The higher magnification of image (d) shows that even severely altered bones may retain small fragments of structurally-intact bone.

to be more soluble than biogenic ones. Dilute acetic acid is typically used to remove adsorbed and secondary carbonates prior to liberating CO_2 from the presumably clean bioapatite. This pretreatment is not always successful (Koch et al. 1997; Land et al. 1980; Stafford et al. 1991; Wright and Schwarcz 1996). Results from a limited study designed to see how effectively dilute acetic acid removed remineralized bone

from Ohio Valley samples (Appendix G) indicate that these samples may pose problems.

These two observations, that at least some of these Ohio Valley archaeological bone specimens evidence severe alterations of the bone mineral and that acetic acid treatment may not be entirely effective in removing altered bone mineral from some samples, do not imply that reliable $\delta^{13}C$ values on bioapatite cannot be obtained from these samples. To collect such data and demonstrate that they do inform on isotopic diet would require effort beyond the scope of this research. Hence, $\delta^{13}C$ values of bioapatite were not determined here.

Hedges and Millard (1995) observed that significant amounts of protein may remain in bones even when they have experienced substantial physical and/or histological alteration. This lack of correspondence in gross preservation between the mineral and protein fractions was confirmed when Parsche and Nerlich (1997) demonstrated immunohistochemically the preservation of collagen even in the presence of significant focal destruction. Thus, even if the bone mineral fraction has undergone physical and/or chemical alterations, there is no reason to assume that the protein fraction has been rendered unsuitable for dietary studies.

Evaluating "Collagen" Integrity

Before presenting the results of the isotopic analysis, the integrity of the extracted material must be established. Briefly, my extraction protocol involved mechanical cleaning of the bone, followed by dissolution of the mineral fraction in dilute acid; the demineralized bone was gelatinized in slightly acidic hot water, filtered, and freeze-dried (Brown et al. 1988; Greenlee 1998). Appendix D presents in greater detail the extraction protocol used, compares it with two alternative protocols (NaOH pretreatment and ultrafiltration), and assesses its associated errors. As reported in Chapter Four for the previously-analyzed "collagen" samples from the Ohio Valley, the results of tests aimed at evaluating the integrity of the

"collagen" product obtained from the Ohio Valley samples analyzed in *this* research are presented.

Yield

Figure 47 shows the relationship between "collagen" yields (mg extract/mg dry bone) from two replicate extractions for each of the samples analyzed here (Appendix F). The error associated with each yield determination is smaller than the individual points and, thus, it does not show on the graph. As might be expected, there is a significant, positive relationship ($r = .948$; $p < .001$) between the "collagen" yields of the two independent replicate extractions. The nature of the relationship is depicted in Figure 47 as a least-squares regression line. Variation along the line reflects interbone variation in "collagen" preservation; variation perpendicular to it reflects intrabone variation in "collagen" preservation and error associated with the extraction and weighing procedures.

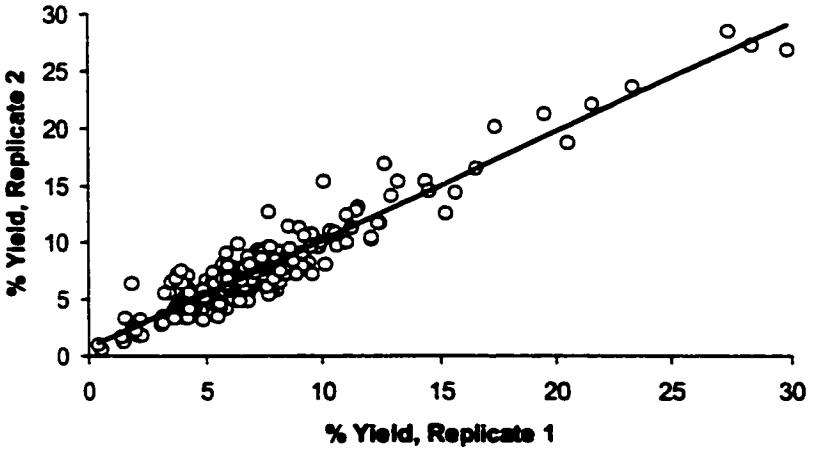


Figure 47. **"Collagen" yields from replicate extractions of archaeological human bone samples.** The line is a product of least-squares regression (y = 0.680 + 0.948x).

The second extraction frequently produced a greater yield, probably because of its often better-protected interior location. Indeed, the constant in the

equation for a least-squares regression line that fits the data is significantly greater than zero ($t = 4.013$; $p < .001$). Furthermore, a paired-sample t-test indicates the difference in yield between the two extractions is significant at $\alpha = 0.05$ ($t = -3.661$; $p < .001$). That the slope of the regression line is less than one suggests that the increased yield of the second extraction (over the first one) is relatively greater in poorly-preserved as compared to well-preserved samples.

Figure 48 plots the distribution of average "collagen" yields for these 251 individuals. The mean yield (± 1 SD) for all individuals is 7.320 ± 4.075; this mean is less than for previously-analyzed samples from the region, but the standard deviations overlap substantially. As with the previously-acquired Ohio Valley data, the distribution departs significantly from normality ($Z = 2.761$; $p < .001$), with greater frequencies of smaller yields indicating a greater abundance of more poorly

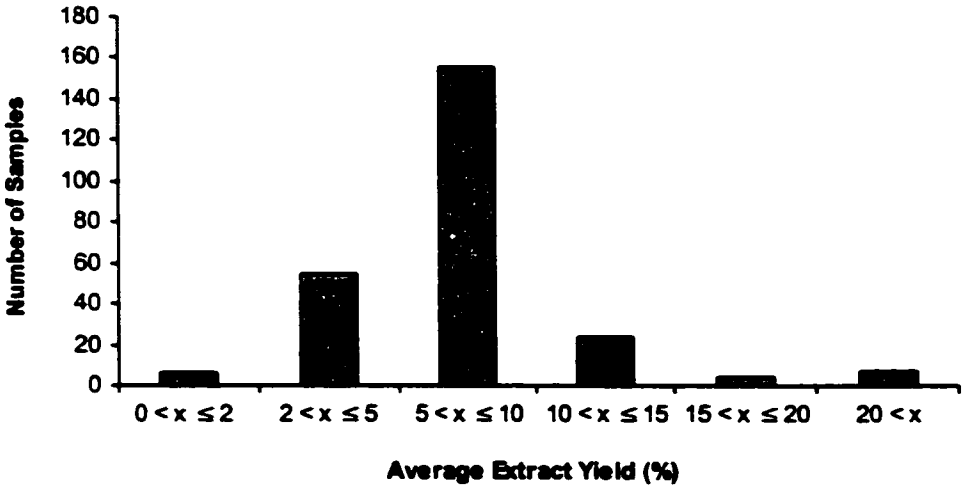


Figure 48. **Distribution of "collagen" extract yield data (average of replicate extractions).**

preserved bones. Still, all but ten individuals provided a "collagen" yield clearly above the 2% empirical threshold and should be primarily "collagen." Six individuals have one yield above and one below the threshold, and both yields are below the threshold for four individuals. Accordingly, for the majority of samples,

one would expect other measures of extract quality to indicate excellent "collagen" integrity. For the ten low-yield individuals, having low "collagen" yields is not sufficient to eliminate them from further consideration, but they will receive particular attention when evaluating other aspects of extract quality.

Carbon and Nitrogen Composition

Carbon and nitrogen concentrations were determined for 94 individuals using a CHN microanalyzer; elemental C/N ratios were calculated from those data (Appendix F). Figure 49 shows the relationship between "collagen" yield and elemental C/N ratio for those individuals. Nine individuals with C/N ratios outside the accepted range of 2.9 – 3.6 are indicated by filled points and all of them have "collagen" yields less than 5.0%. Although all nine of the "unacceptable" samples have high C/N ratios, only two exceed 3.6 by more than 2 standard deviations; given the number of measurements, measurement error could account for some of the high C/N ratios, but their close association with low-yielding samples ($Z = 2.349$; $p < .001$) makes it unlikely.

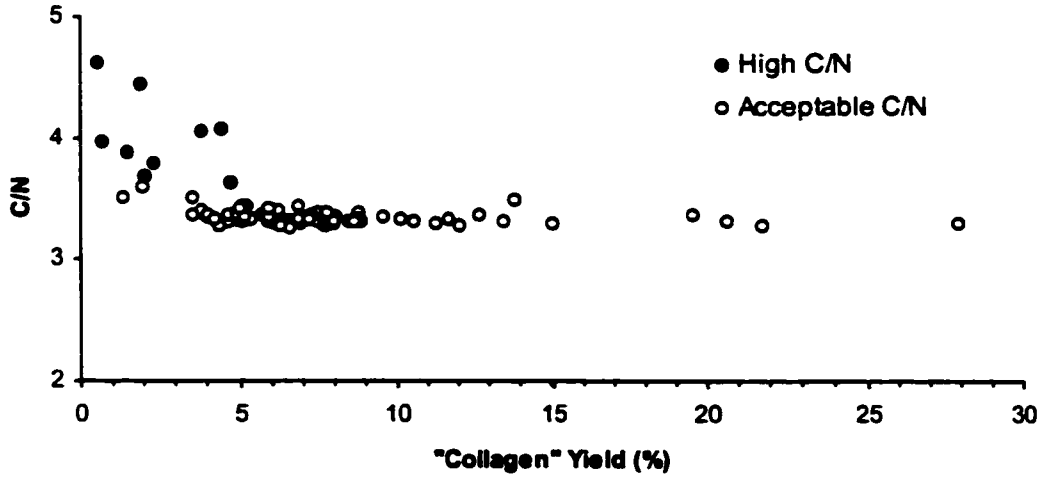


Figure 49. **C/N ratio vs. "collagen" yield.** Filled points indicate C/N ratios greater than the "acceptable" range of 2.9 – 3.6.

Figure 50 plots C/N ratios for eight of these nine individuals[29] against their deviations from the mean $\delta^{13}C$ values for their respective skeletal assemblages. Four of the eight individuals plotted are slightly enriched compared to their means, while the other half is clearly depleted. There is no clear overall trend to the data, but within locales, $\delta^{13}C$ values tend to be more depleted as the C/N ratio increases. The $\delta^{13}C$ values differ from their means by less than 2 ‰, the estimated dietarily significant difference.

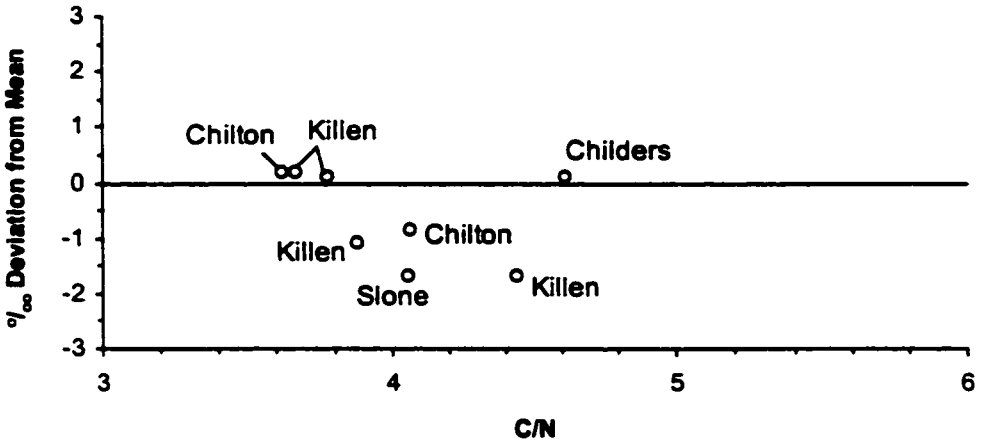


Figure 50. **C/N ratio versus deviation from mean $\delta^{13}C$ for samples with C/N ratios outside the "acceptable" range of 2.9 – 3.6.**

[29] The ninth individual was from Campbell Island. Although two other individuals from there were analyzed, they were both significantly more enriched (-13.66 and -14.46 ‰) than the one of interest (-20.34 ‰). That such a great difference could be one of diet, not preservation, argues against comparing with the mean at that locale. The assemblage from Childers was also composed of both depleted (-20.72 and -20.38 ‰) and enriched (-11.41, -13.25, -13.49, -13.51, and -12.79 ‰) individuals. Since that magnitude of difference between these groups is probably due to different diets, it makes the most sense to compare the individual having an "unacceptable" C/N ratio (-12.79 ‰) with the mean of the individuals to which it is isotopically similar, the enriched ones.

Carbon and nitrogen concentrations are plotted against "collagen" yield in Figure 51 for the same 94 individuals with C/N ratios. The filled points indicate samples with C/N ratios outside of the accepted range. Only one individual from Childers has a nitrogen concentration (%N = 5.095%) outside the range of modern collagen; none have carbon concentrations outside the modern range. Perhaps the most striking observation about this plot is how carbon and nitrogen concentrations decrease in samples with "collagen" yields less than 5%. Ambrose (1990) found, in his analysis of "collagen" in archaeological human bones from East Africa, a similar pattern of declining %C and %N as "collagen" yields decreased below 5%. Although he noted an abrupt drop in %C and %N for samples with "collagen" yields less than 2%, such is not apparent here.

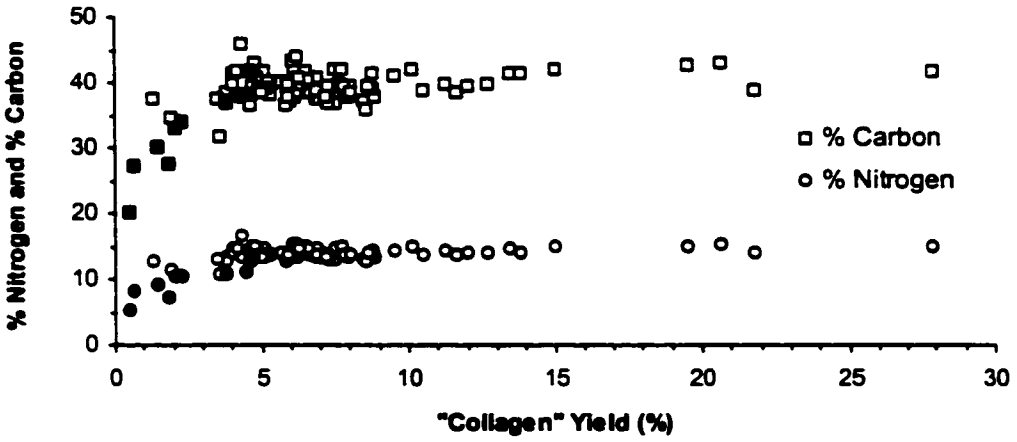


Figure 51. **Nitrogen and carbon concentrations versus "collagen" yield.** Filled points indicate samples with C/N ratios outside the range 2.9 - 3.6.

From the above, it would appear that carbon concentration in "collagen" might itself be a useful screening device for those samples not measured with the CHN microanalyzer. Carbon concentrations were obtained manometrically for "collagen" replicates as the CO_2 samples were being prepared for isotopic analysis (Appendix F). The manometrically-acquired carbon concentrations, although consistently greater, are significantly and linearly correlated with those

from the CHN microanalyzer ($r = .799$; $p < .001$). Figure 52 plots manometrically-acquired %C versus "collagen" yield for all of the individuals examined in this research. Again, all of the "collagen" samples examined have carbon concentrations within the range of modern collagen.

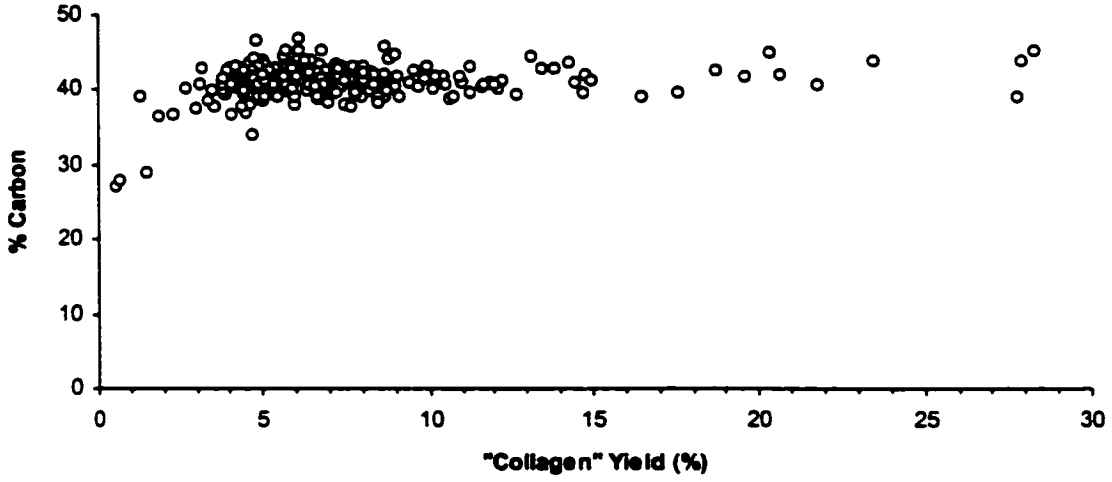


Figure 52. **Manometrically-acquired carbon concentrations in "collagen" versus "collagen" yield.**

Amino Acid Composition

Amino acid compositions were determined for "collagen" from 31 individuals analyzed for this research (Appendix F). Those data are plotted in Figure 53. For comparison, the distributions of modern human bone collagen, noncollagenous proteins and exogenous noncollagenous amino acids are plotted as well. It is quite apparent that the protein in the extracted "collagen" is very similar to modern, unaltered human bone collagen. This is so even for samples that were characterized by low "collagen" yields and/or high C/N ratios. The protein fraction (total amino acid weight %) of the "collagen" from all 31 samples averages (± 1 SD) 63.444 ± 10.296%. This estimate is best taken as a minimum because (1) the "collagen" is sometimes hygroscopic (the adsorbed water means sample weights overestimate the amount of material, and it makes the sample "sticky" and difficult

to ensure a complete transfer from the weighing boat to the ampule) and (2) some amino acids may be altered (e.g., complexed to other materials) and thus will not follow established separation sequences through the column.

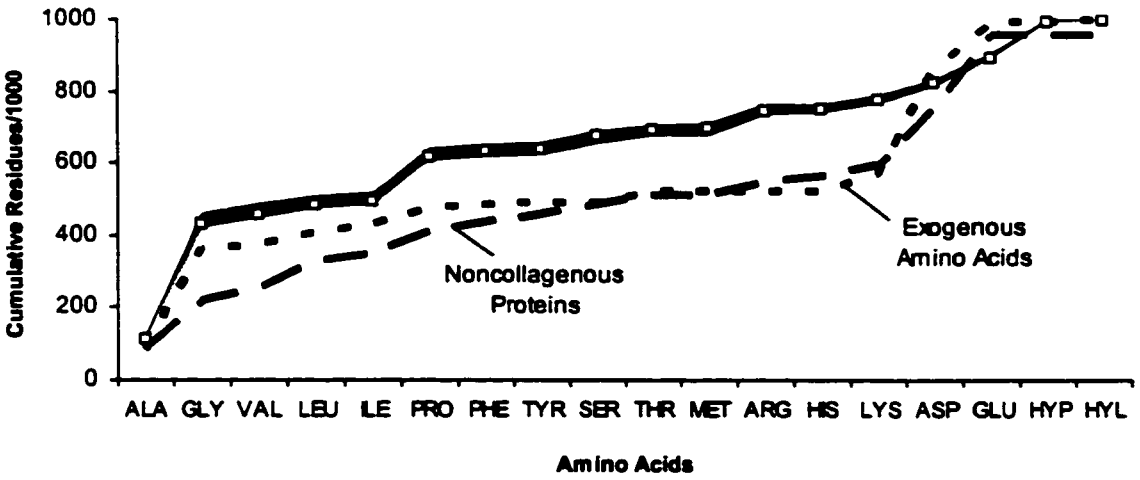


Figure 53. **Amino acid composition of 31 archaeological "collagen" samples.** Archaeological samples (thin black solid lines) are compared to modern collagen (thin white line with □ symbols), modern noncollagenous proteins and exogenous amino acids from a prehistoric mammoth bone. ALA, alanine; GLY, glycine; VAL, valine; LEU, leucine; ILE, isoleucine; PRO, proline; PHE, phenylalanine; TYR, tyrosine; SER, serine; THR, threonine; MET, methionine; ARG, arginine; HIS, histidine; LYS, lysine; ASP, aspartic acid; GLU, glutamic acid; HYP, hydroxyproline; and HYL, hydroxylysine.

The presence of collagenous versus noncollagenous proteins can also be assessed using ratios of different amino acids. One ratio, glycine (GLY) to aspartic acid (ASP), is large in well-preserved "collagen" and is small when exogenous amino acids and noncollagenous proteins predominate (Hedges and van Klinken 1992 and references therein). For the comparative samples[30] in Figure 53, GLY:ASP is 6.79 in modern collagen, 0.78 in noncollagenous proteins, and 0.95 in the noncollagenous exogenous amino acids. Among the archaeological samples, GLY:ASP ranges from 5.92 to 7.49, with a mean (± 1 SD) of 6.77 ± 0.34. They are

[30] Estimates of measurement error were not reported for these comparative data.

indistinguishable as a group from modern collagen, indicating again that the archaeological "collagen" samples are relatively well preserved.

"Collagen" Preservation

This evaluation of "collagen" integrity indicates that most of the archaeological human bone samples considered in this research meet expectations of "collagen." Like the previously-analyzed Ohio Valley samples discussed in Chapter Four, they are reasonably well preserved, with adequate "collagen" concentrations, and the C/N ratios, carbon and nitrogen concentrations, and amino acid profiles are characteristic of modern values. Thus, for most, diagenesis can be eliminated as a significant source of variability in the stable carbon isotope ratios; the $\delta^{13}C$ values should reflect biological levels at the time of death. Throughout this work, the few specimens with low yields and/or high C/N ratios are closely monitored and they are included only when they do not impact significantly the conclusions drawn about isotopic diet.

STABLE CARBON ISOTOPE DATA

Figure 54 plots my newly-generated $\delta^{13}C$ values for "collagen" from Ohio Valley populations (Appendix F) and the previously-collected isotope data. Fifteen individuals for whom age is not known and seventeen individuals that predate A.D. 1 are not shown. The Late Woodland samples, which fill a large gap in the existing isotopic record, are particularly valuable because of the understanding they allow into how maize farming may have spread. The new measurements also expand our spatial and temporal coverage in a way that allows new insights into the record of isotopic dietary variation. From this point forward, the previously-collected and my newly-generated isotopic measurements are combined, treating them as a single data set for comparison with other traditional archaeological variables.

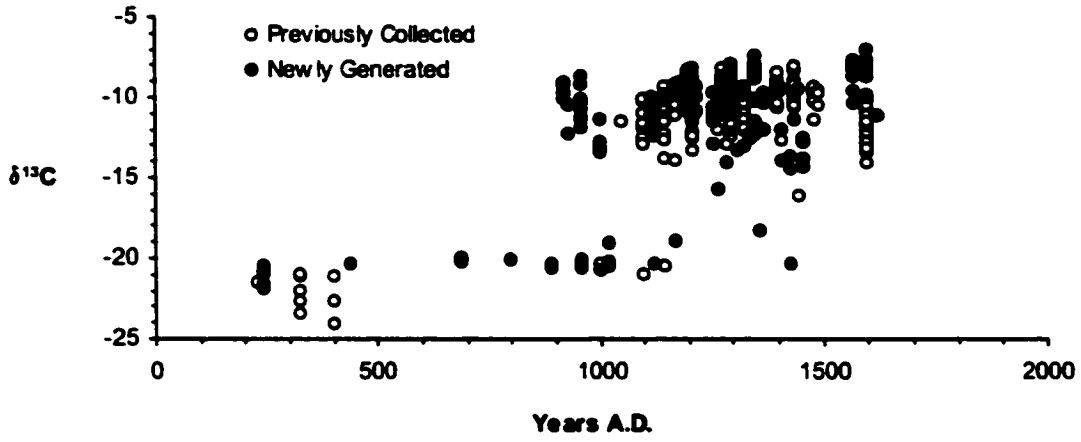


Figure 54. **Newly-generated (n = 219) and previously-collected (n = 214) stable carbon isotope evidence for maize consumption in the middle and upper Ohio Valley.** At this scale, error associated with replicate measurements is smaller than the plotted data points.

TIMING

In the light of new data on some skeletal populations and a subsequent reevaluation of the age of others, it now appears that changes in isotopic diet that reflect significant consumption of maize probably did not occur in the region much earlier than the later part of the Late Woodland period, ca. A.D. 900 (contra Greenlee 2001a). Radiocarbon determinations have been obtained on isotopically enriched individuals from three Late Woodland deposits, Turpin, Varner and W. S. Cole. In calendar years A.D. [1σ (intercept) 1σ], those determinations were [781 (892) 979], [781 (897, 922, 942) 997] and [889 (902, 917, 962) 993], respectively. The Turpin and W. S. Cole radiocarbon dates were acquired as part of this research; the Varner date is published in Sciulli (1995). Interestingly, these individuals, which are virtually the same age, are from locales geographically quite distant from each other. Certainly, as more samples from the relevant time range are analyzed, the initial appearance of maize farming may be pushed back somewhat.

TEMPO

Although some gaps still remain in the Ohio Valley sequence, the data thus far do not appear to support the commonly-held notion that maize became a dietary staple gradually there. If anything, the dietary change documented here can be considered as having occurred rather abruptly, presumably within a generation or so. I do not imply that the entire population of the entire region changed its diet within one generation, but wherever and whenever that dietary change occurred, it did so very rapidly. Of course, it is possible that individuals with "transitional" values (i.e., -19 – -15 ‰) that would provide evidence of a gradual change early in the sequence were missed in this sample. If such individuals did exist and if my sample is not strongly biased in some unknown way, they must be of very low frequency. Only seven (2.789%) of the 251 individuals analyzed had "transitional" values.

What of the seven individuals that do have "transitional" values? Five are shown in Figure 54 and two more [one each from Upper Valley locales, Barn (-15.93 ‰) and A. M. Byer (-16.78 ‰)] are unplotted because their ages are unknown beyond Late Prehistoric and Late Woodland, respectively. Although, with the possible exception of the individual from A. M. Byer, they are too recent to be evidence for a gradual change from hunting/gathering/gardening EAC plants to maize farming for the region as a whole, they could conceivably reflect that change within the trajectory from a particular area. It might be valuable to examine the isotopic trajectory in an area where "transitional" individuals are found; perhaps maize farming appeared later there than in other parts of the study region, thus making it possible that the "transitional" individuals would be found in the early part of that sequence.

Four of the "transitional" individuals are from southwest Ohio. Figure 55 plots the trajectory of isotopic diet change among locales from the drainages of the Great and Little Miami Rivers. The data points are relatively few

(n = 128 from 15 deposits), but the pattern does not meet expectations for a gradual transition, nor does maize farming seem to appear significantly later than in other parts of the study area. Future mass spectrometric analysis using laser ablation may permit demineralized bone to be sampled histologically, thus allowing comparison between new and old "collagen" in these "transitional" individuals to distinguish whether they had recently changed their diet from nonmaize- to maize-consumption or vice versa, or if they consistently ate an intermediate diet.

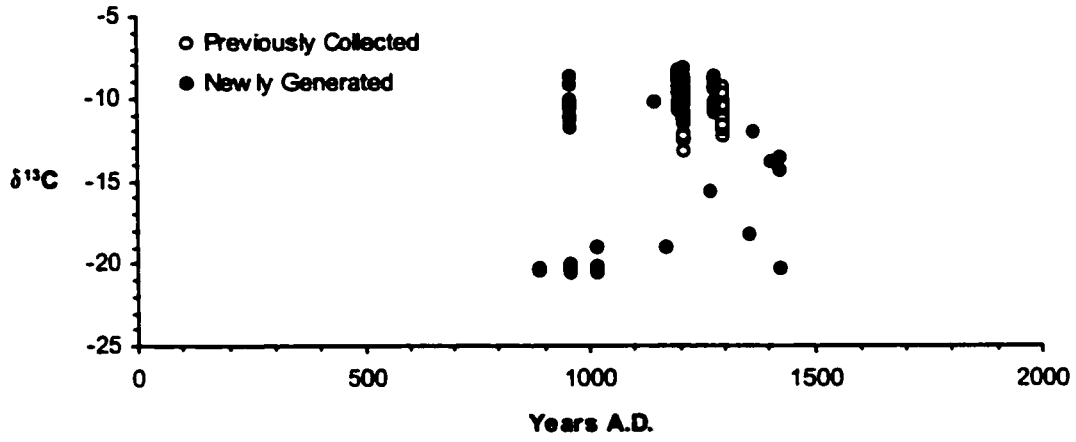


Figure 55. **Trajectory of isotopic diet change in southwest Ohio.**

The new data presented in Figure 54 would seem to support the idea that, once established, maize consumption did increase slowly throughout the Late Prehistoric period and to imply that the previously-noted trend toward a decline in maize consumption after ca. A.D. 1400 was an artifact of sampling. When the data set is divided into middle and upper Ohio Valley samples (Figure 56), however, it appears that isotopic diet in the two areas followed different trajectories. In the middle Ohio Valley, a post-A.D. 1400 decrease in maize consumption is still apparent, while in the upper Ohio Valley, maize consumption appears to have increased through time. Why this might be so will be addressed in greater detail later.

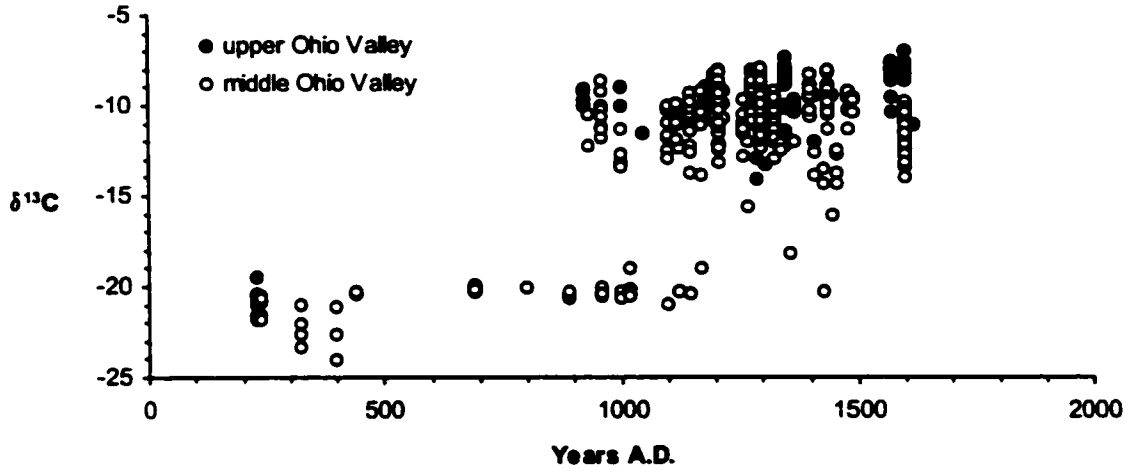


Figure 56. **Stable carbon isotope data for middle and upper Ohio Valley populations.**

Regional trajectories may tend upward or downward because maize consumption did increase or decrease or because the composition of the sample varies (from one set of circumstances to another) with time. Accordingly, it might be instructive to examine dietary change as reflected by individuals from different times at particular locations. There are three locales (Saddle, Turpin and Slone) where isotope ratios have been collected for individuals that are assignable to different occupations. Those three examples show fundamentally different patterns of change through time in isotopic diet.

At Saddle, archaeologists assumed, as many do, that dietary commitment to maize increased through time (Church 1995). The frequency of dental caries, which tends to increase as carbohydrate consumption increases, does not support that assumption (Sciulli and Church 1995); instead, there appears to be a slight decrease in caries, and presumably carbohydrates, through time. $\delta^{13}C$ values obtained here for seven individuals (three from an early Late Prehistoric occupation [ca. A.D. 1200] and four from a later one [ca. A.D. 1400]) are consistent with the latter observation. The isotopic composition of the early individuals (mean

± 1 SD = -9.38 ± 0.42 ‰) differs from that of the later ones (mean ± 1 SD = -10.02 ± 0.34 ‰), but not significantly so at $\alpha = .05$ ($t = 2.219$; $p = .077$).

The Turpin case is somewhat more complicated. The burials have been partitioned into three sets: one set from a Late Woodland stone mound (ca. A.D. 950), one set from an early Late Prehistoric earthen mound, and a third set from a Late Prehistoric cemetery that circles the earthen mound (the cemetery is actually an oval ring hugging the mound closely on one end and enclosing a large vacant space on the other). The burials in the stone mound are clearly older than those from the earthen mound and cemetery, but the temporal relationship between the cemetery and the earthen mound is unclear. The use of burial mounds among Late Prehistoric groups in the Ohio Valley tends to be early (Drooker 1997; Graybill 1981) and one might suppose that because the ringed cemetery hugs the mound on one end, the mound was already there when the cemetery was in use. The remainder of the vacant area is difficult to explain, though; it may reflect the original extent of the mound (Oehler 1973) or it may represent a village plaza. The latter makes sense given that different functional classes (e.g., hearths, structures, graves, storage pits, midden) produced by different activities in Late Prehistoric villages in the region are often zoned concentrically around an empty plaza (Dunnell 1983; Dunnell et al. 1971). The cemetery is *probably* more recent than the earthen mound, but this is not definite by any means.

Individuals from the stone mound at Turpin fall into two groups; 50% are depleted, consistent with no maize consumption, and 50% are enriched, consistent with significant maize consumption. All individuals from the other two settings are enriched.[31] The mean isotopic composition of individuals from the Late Woodland stone mound (mean ± 1 SD = -15.466 ± 5.213 ‰) is less than that of the

[31] Although van der Merwe and Vogel (1978) reported enriched $\delta^{13}C$ values for ten individuals from Turpin, they did not indicate the context of those burials. Consequently, those data cannot be included in this comparison.

Late Prehistoric earthen mound (mean ± 1 SD = -10.24 ± 0.748 ‰), which is less than that of the cemetery (mean ± 1 SD = -9.121 ± .746 ‰). The variance for the Late Woodland stone mound sample is much larger than for the two Late Prehistoric contexts and so it is not surprising that a Levene's test for homogeneity of variance indicates that the variances differ significantly ($F = 219.727$, $p < .001$). Thus, ANOVA is not an appropriate statistical tool for comparing these samples. A Kruskal-Wallis test indicates that the three samples are drawn from different populations ($\chi^2 = 13.789$; $p = .001$).

When only the maize-consuming individuals from the Late Woodland stone mound sample are considered (mean ± 1 SD = -10.47 ± 1.078 ‰) in comparison to the Late Prehistoric samples, ANOVA indicates the differences are significant ($F = 5.061$; $p = .016$), and Tukey's Honestly Significant Difference test indicates that the cemetery differs significantly from both the earthen mound ($p = .047$) and the stone mound ($p = .018$) and the latter two do not differ from each other ($p = .851$). Thus, although the proportion of nonmaize consumers did change tremendously between the Late Woodland and initial Late Prehistoric occupations at Turpin (from half to none of the samples, respectively), there was apparently little change in the isotopic diets of maize consumers during that time; over the course of the Late Prehistoric occupation, though, people apparently did consume greater amounts of maize. If additional research finds that the cemetery and the earthen mound are coeval, then we must consider some other explanation.

Change in the isotopic record through time at Slone is also quite interesting. The locale was occupied three times, as evidenced by three distinct palisade lines of increasing circumference (Figure 57). Because different classes of materials were distributed concentrically at Slone and because graves tended to be located in zones just inside the palisades, the burials can be subdivided into three occupations based on their locations relative to the palisades. The probability of error in assigning burials to occupations decreases mechanically from the earliest to

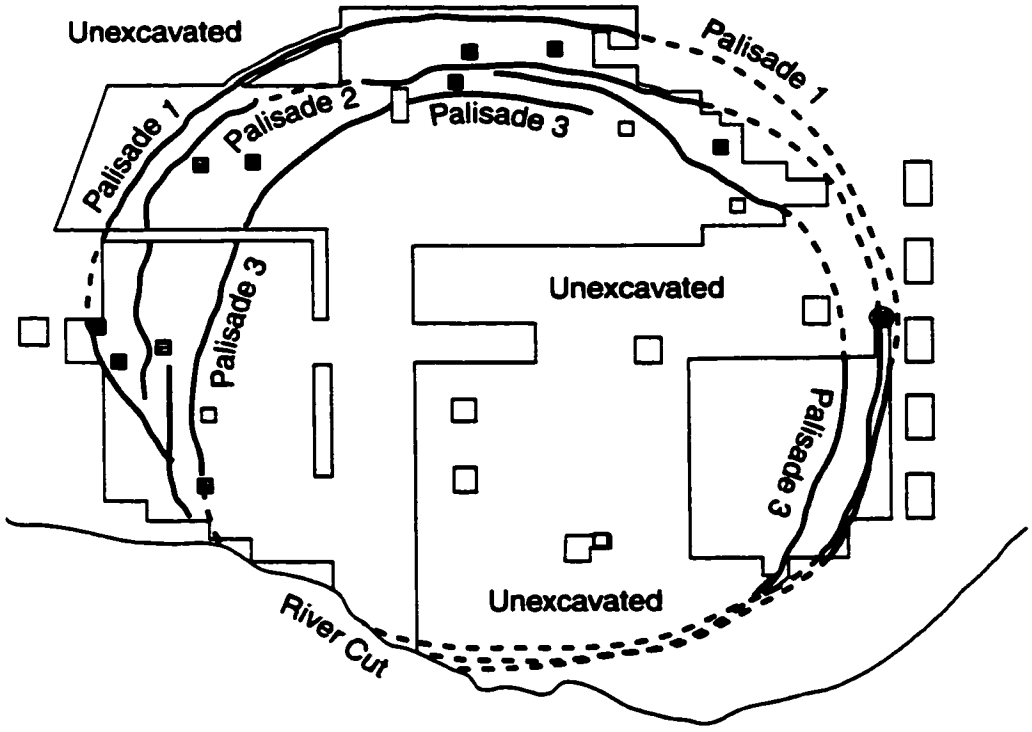


Figure 57. **The Slone locale.** Map showing the palisades (solid lines follow paths of postmolds; dashed lines indicate expected paths) and the locations of burials with $\delta^{13}C$ data. Redrawn from Dunnell et al. (1971). Squares indicate the locations of burials, with white fill indicating those assigned to the first occupation, gray fill indicating those assigned to the second occupation and black fill indicating those assigned to the third occupation.

the latest occupations. Those burials located inside the last and largest palisade (Palisade 1) are quite likely to be associated with the last occupation; those located inside the middle palisade (Palisade 2) are likely to be associated with the second occupation, but one or more might belong to the latest one; those located inside the smallest palisade (Palisade 3) are likely associated with the first occupation, but one or more could belong to the middle or even the last occupation. Figure 57 locates isotopically-analyzed burials relative to the identifiable palisade lines and identifies each as to its probable occupation.

Figure 58 plots the $\delta^{13}C$ values for individuals from each of the occupations. The mean isotopic compositions do not seem to vary significantly among the occupations (mean ± 1 SD: 1st occupation, -9.56 ± 1.63 ‰; 2nd occupation, -10.08 ± 0.59 ‰; 3rd occupation, -9.6 ± 0.39 ‰); the variances appear to be unequal, however. The $\delta^{13}C$ values for individuals from the initial occupation show a large spread, much greater than for subsequent occupations. Indeed, Levene's test for homogeneity of variance indicates the variances differ significantly between the three groups ($F = 12.721$; $p = .001$). Consequently, ANOVA is inappropriate to compare the samples. A Kruskal-Wallis test indicates they do not differ significantly ($\chi^2 = 1.694$; $p = .429$). Recall that one individual from Slone analyzed in this research had a C/N ratio outside the accepted range; removing that individual from consideration does not change any of these conclusions.

Why would there be greater variation in isotopic diet initially? Perhaps the nucleated community at Slone was formed by the aggregation of individuals from different dispersed groups who consumed, over their lifetimes, different diets; thus, they came with different isotopic backgrounds that had not yet equilibrated. Or perhaps the isotope ratios reflect what evolutionists call centripetal (Simpson 1984) or stabilizing selection; in centripetal selection, the modal variant is more fit than variants in any direction and selection reduces variation around the mode. So, diets were more variable initially due to greater environmental diversity in the new environment, but over time, the fitness of variant diets decreased as the maize agroecology was established. If future research can more definitively associate individuals with their occupations (using, e.g., fluorine concentrations in bone to establish relative order of interment), then isotopic and/or trace element concentrations in teeth may allow us to establish how variation in childhood diets was distributed; a positive correlation with the adult data would support the first hypothesis.

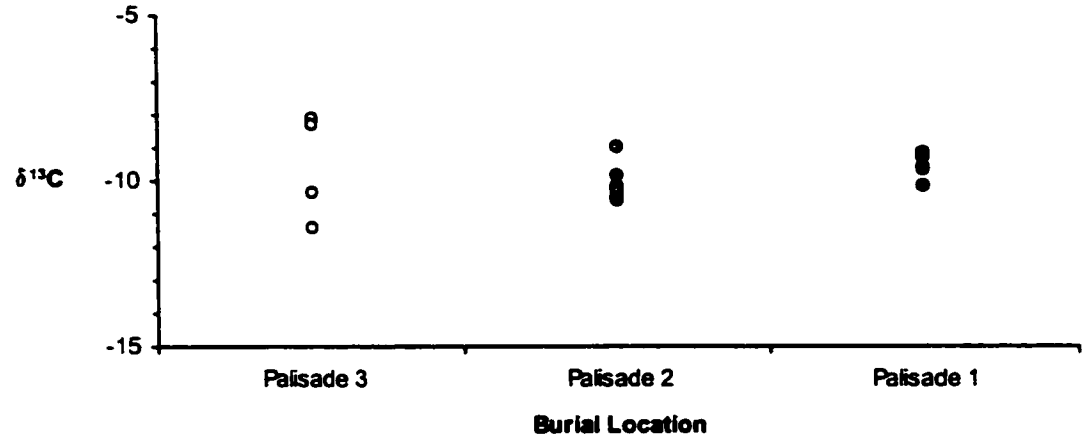


Figure 58. **Isotopic composition of individuals based on their locations with respect to the palisades at Slone.** Palisade 3 is from the earliest occupation and Palisade 1 is from the latest one (see Figure 57). All but two $\delta^{13}C$ values are from Broida (1983).

STRUCTURE

The temporal distribution of stable carbon isotope values in the middle and upper Ohio Valley as shown in Figure 56 is more like Figure 26c than 26b. The appearance is clearly more punctuated than gradual. There is evidence for two distinct populations, one reliant upon maize and one not, with few intermediate individuals; the few intermediates occur midway in the sequence and not in an early "transitional" segment.

Two Isotopically-Distinct Populations?

Probably of equal interest to the observation that there is no evidence for a gradual "transition" in maize consumption in the Ohio Valley is the apparent long-term continuance of a small population with little or no dietary maize. As mentioned in Chapter Two, whenever these individuals have been encountered in Late Prehistoric contexts, they have been assumed to be associated with earlier occupations at those locales. Establishing the ages of those individuals whose diets were not maize-dominated is thus critical. Figure 59 shows the basis for age

assignment of those individuals more recent than A.D. 400 with depleted stable carbon isotope ratios (< -15 ‰). Clearly, more work along this line remains to be done, as too many of these age assignments rest on assumed associations with other dated individuals or materials and some individuals of potential interest cannot be plotted here at all because their ages are simply unknown. Nevertheless,

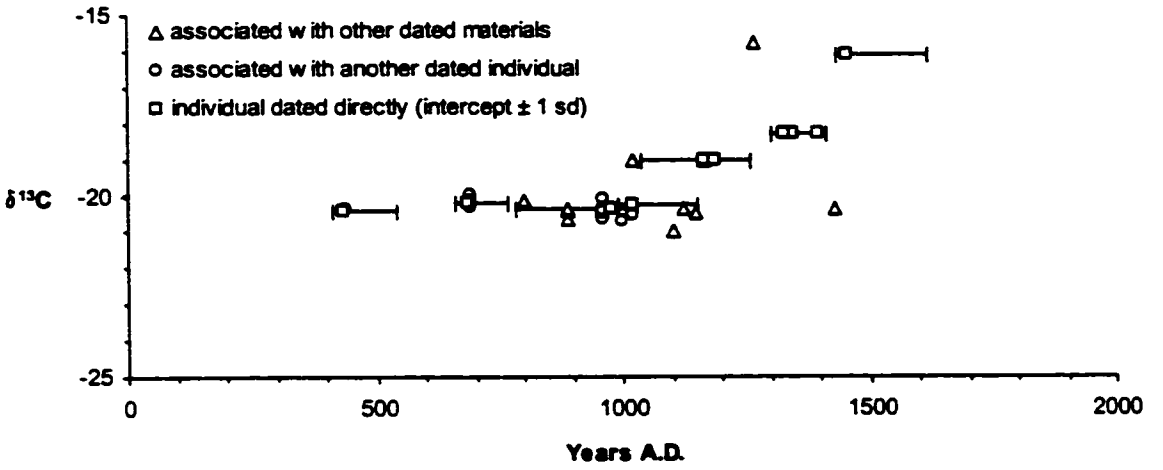


Figure 59. **Method of age assignment for isotopically-depleted individuals (< -15 ‰) from the Late Woodland and Late Prehistoric periods.**

radiocarbon dates of "collagen" from isotopically-depleted individuals support the notion of a small population that continued to eat significantly less maize than did the majority of Late Prehistoric-aged individuals from the region. If the relative abundance of enriched and depleted individuals is not an artifact of sampling, the pattern suggests that the population for whom maize was a dietary staple was more successful in an evolutionary sense.

Figure 60 shows the geographical distribution of the post-A.D. 850 isotopically-depleted population. All of the individuals are from the middle Ohio Valley (except for two individuals from the Upper Valley whose locations are not precisely known and, thus, cannot be plotted) and most of them are concentrated in

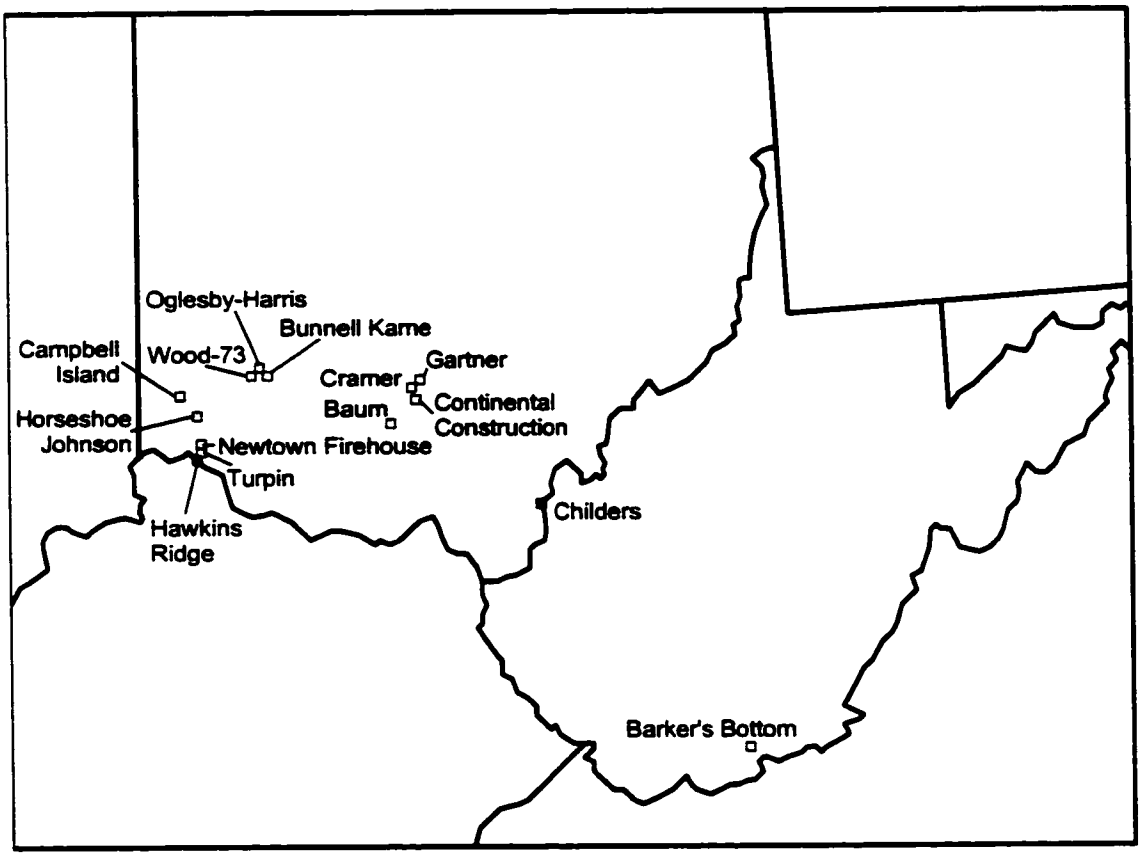


Figure 60. **Geographic distribution of post-A.D. 850 isotopically-depleted individuals.**

southwestern Ohio. From this distribution, it appears that one or more small populations not committed dietarily to maize continued to inhabit the study area, concentrated in SW Ohio, long after the appearance of specialized maize-based farming systems. There can be no doubt that the environment was productive enough to support small populations without a maize base (as it had for thousands of years prior to maize farming), but this is the first real evidence for the continuance of such a population into the Late Prehistoric period. How these individuals were distributed is a question of interest: Did these individuals belong

to one or more communities, living separate from those reliant on maize,[32] or did they belong to the same communities as those whose diets relied on maize?

One way to begin addressing this question is to examine the burial assemblages to which the relatively depleted individuals belong. If the assemblages are comprised by only depleted individuals or if depleted individuals are rare (and perhaps exhibit evidence of burial treatment different from the rest) in assemblages dominated by enriched individuals, that would suggest depleted individuals formed a distinct population. If depleted individuals form a significant proportion of burial assemblages that also have enriched ones, that would suggest they were part of the same communities as the enriched individuals, but simply maintained a different diet. Evidence that the depleted and enriched individuals were contemporaneous would be necessary to show that they were part of the same interacting group of people.

Figure 61 plots the post-A.D. 850 isotopically-depleted individuals relative to the entire sample analyzed from their respective burial assemblages. There is substantial variation in the way isotopically-depleted individuals are distributed among these assemblages. They represent the entire sample for six small assemblages: Continental Construction, Wood-73, Oglesby-Harris, Horseshoe Johnson, Hawkins Ridge and Newtown Firehouse. Eight assemblages are mixed (i.e., they have both relatively-enriched and -depleted individuals), but, for half of them, three or fewer individuals have been analyzed and the individuals are very likely not contemporaneous at two of those locales (Barker's Bottom and Bunnell Kame; see Figure 61 caption). Of the four mixed assemblages with greater than five individuals, only two have more than one relatively depleted individual; for Childers, 2/7 (28.5%) are depleted, while for Turpin, 8/16 (50%) are. With the

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[32] For central Ohio, at least, there is a long-standing idea that populations who resisted the "Mississippian" way of life moved into the hilly hinterlands and continued living their "Woodland" lifestyles (e.g., Prufer and Shane 1970).

exception of Turpin, and perhaps Childers, these data appear to support the notion of a separate population of non-maize consumers throughout at least some of the Late Prehistoric period in some places.

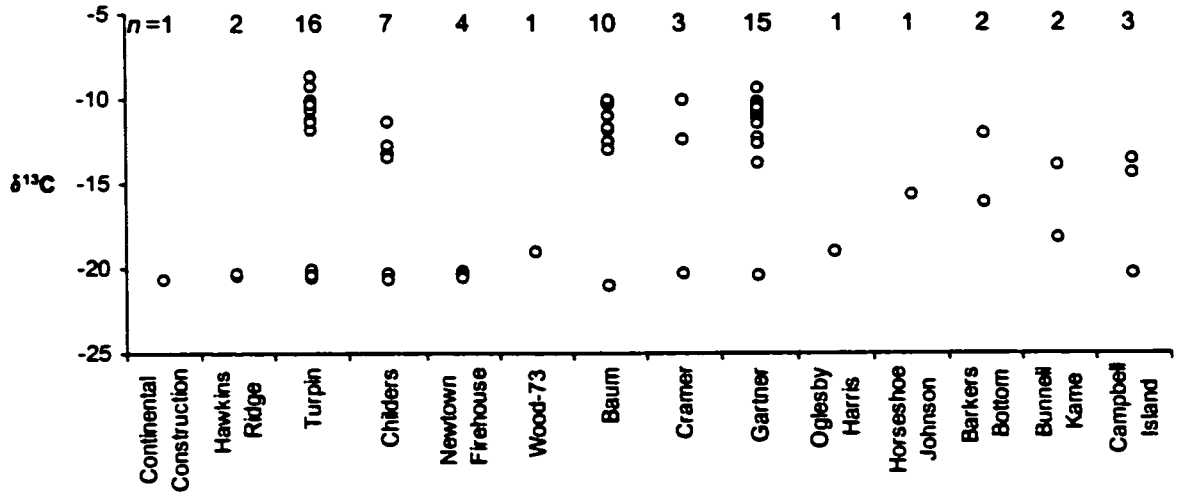


Figure 61. **$\delta^{13}C$ values and number of individuals analyzed from locales with post-A.D. 850 isotopically-depleted individuals.** The locales are in rough chronological order. The relatively enriched individual from Barker's Bottom is older (ca. A.D. 1270) than the depleted one (ca. A.D. 1450), while at Bunnell Kame the relatively enriched individual is younger (ca. A.D. 1410) than the depleted one (ca. A.D. 1360).

With half of the 16 individuals analyzed being enriched and the other half being depleted, variation in isotopic diet among individuals from the late Late Woodland stone mound at Turpin is worthy of further exploration. Figure 62 shows how $\delta^{13}C$ values vary among individuals with respect to sex and age-at-death. There are no relationships among those variables. Although no data have been compiled specifically regarding hypothesized indicators of individual status (e.g., burial goods and/or treatment), all of the individuals analyzed here were identified as "partial burials," apparently indicating that the skeletons were anatomically incomplete.

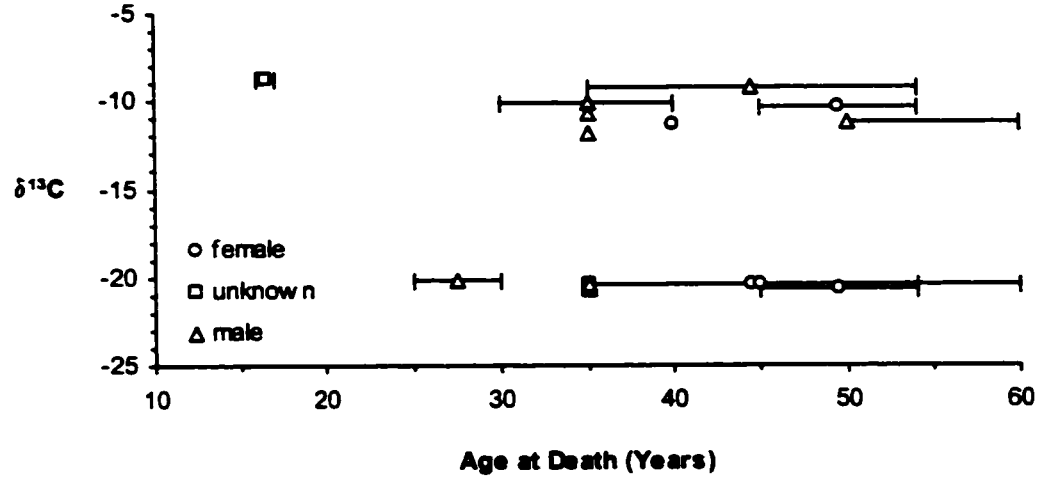


Figure 62. **$\delta^{13}C$ values versus age-at-death and sex for individuals from the Turpin Stone Mound.** Individuals for which the age determination was simply "adult" have been arbitrarily plotted at age 35.

Another hypothesis is that the population inhabiting the Late Woodland village at Turpin aggregated from communities that consumed distinctly different isotopic diets; perhaps everybody did consume high-maize diets at Turpin, but the bones of the depleted individuals had not yet equilibrated. Since the depleted individuals show *no* evidence of enrichment (when compared with clearly non-maize consuming individuals from earlier time periods), this is an unlikely scenario. It necessitates the deaths of those individuals before their bodies could incorporate many carbon atoms from maize.

It remains a possibility that these individuals were interred at different times (e.g., all depleted individuals were deposited at an earlier time during the Late Woodland than the enriched ones or that the enriched individuals are intrusive Late Prehistoric burials). It is thus critical that the timing with which they were deposited in the mound be established. High precision radiocarbon dates might have sufficient resolution to distinguish some different death events. If the post-depositional environment can be established as comparable in terms of the mechanisms of fluorine exposure among individuals, fluorine analysis could be

useful in establishing a relative burial sequence. Ongoing research by Pat Tench on the Turpin Stone Mound burial population and her "reconstruction" of the mound layout will be particularly valuable in establishing the stratigraphic order of interments.

Geographic Variation in Isotopic Diet through Time

The newly-acquired stable carbon isotope data have more than doubled the number of locales with such data in the Ohio Valley. Thus, it is not only possible to see how isotopic diet varied geographically, as in Figure 25, but within successive time periods (Late Woodland, A.D. 400 – 1000; early Late Prehistoric, A.D. 1000 – 1250; middle Late Prehistoric, A.D. 1250 – 1400; late Late Prehistoric, A.D. 1400 – 1650). Although the number of locales represented is not evenly distributed temporally or geographically, we still can gain insight into how maize-dominated diets occur across the region and assess the role that environmental characters have played.

In Figure 63, mean $\delta^{13}C$ values for locales with more than two contemporaneous individuals and actual values for single individuals identified as Late Woodland in age are plotted. There is considerable variation among these data and some of the variation may be temporal. Most of the more enriched values (W. S. Cole, Varner and Turpin) represent the end of the Late Woodland period; most of the depleted values (Henderson Mound #2 and Zencor) are from individuals deposited earlier in the period, although Hawkins Ridge was apparently a late deposit. Little is known about the age of the locale near North Vandergrift, WV, known to me only as "36AR?" beyond that it is Late Woodland in age (Sciulli, p.c.). Geographically, it appears that the earliest groups dietarily committed to maize were located at the margins of the study region.

Figure 64 similarly shows the distribution of $\delta^{13}C$ values from early Late Prehistoric locales. The pattern of greater maize consumption among

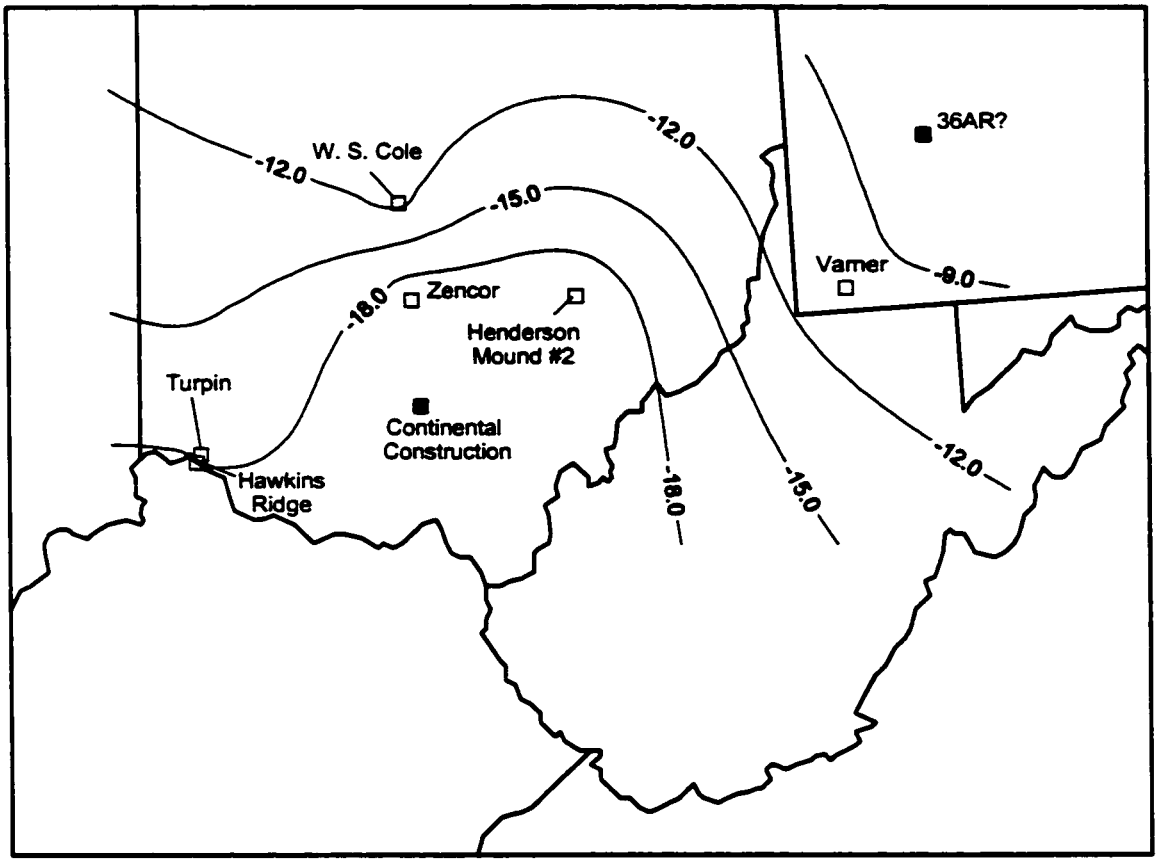


Figure 63. **Geographic distribution of $\delta^{13}C$ values from Late Woodland deposits.** Hollow symbols indicate means for locales with more than two individuals analyzed; solid symbols indicate individual values. All of these data are newly-generated by this research.

geographically marginal populations seen for the Late Woodland data appears to continue into this time period. Southwest Ohio, particularly the Caesar Creek area, stands out as a place where some individuals consumed significantly less maize into the early Late Prehistoric period. The single individual from the Hobson site has a great impact on the geographic patterning of the -10.0 ‰ isoline.

The geographic pattern of isotope values in the early Late Prehistoric period largely continues into the middle Late Prehistoric period (Figure 65). The unusual level of isotopic depletion of some individuals from southwest Ohio is

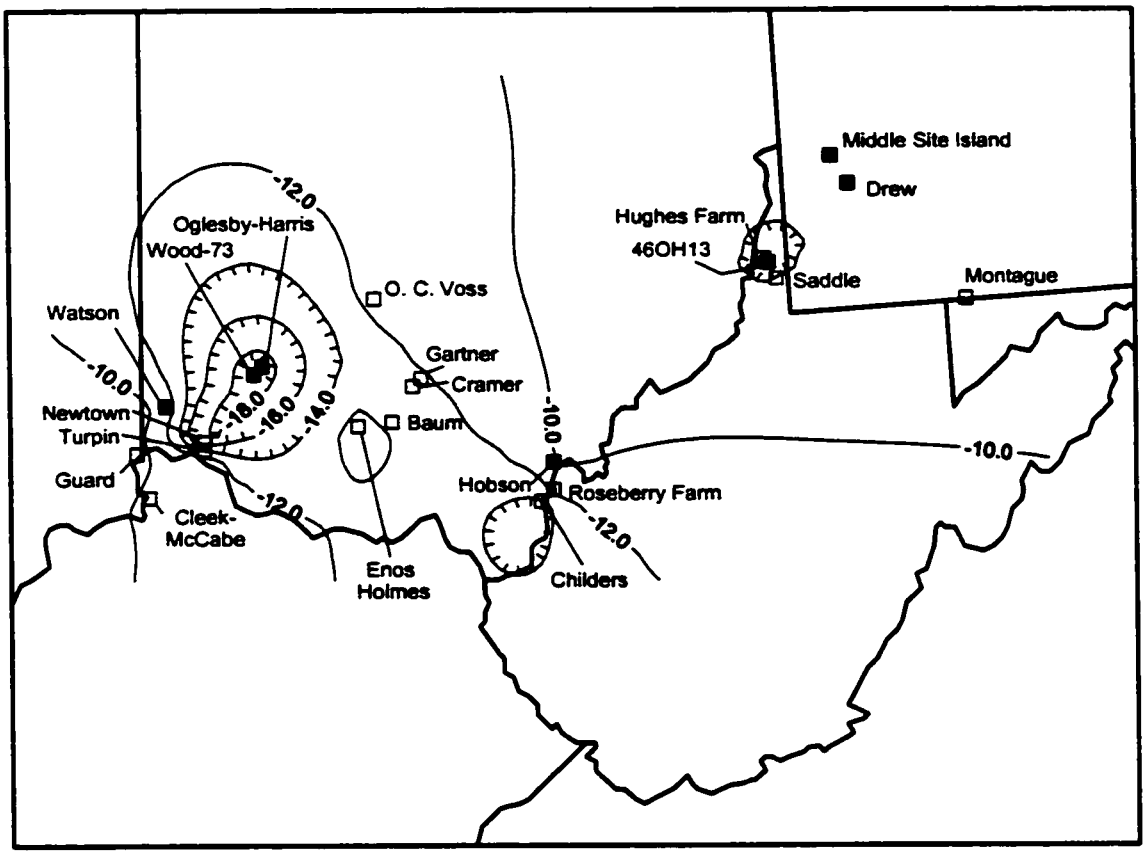


Figure 64. **Geographic distribution of $\delta^{13}C$ values from early Late Prehistoric deposits.** Hollow symbols indicate means for locales with more than two individuals analyzed; solid symbols indicate individual values. All data, except Hughes Farm, 46OH13, Roseberry Farm, Gartner, Baum, 1/7 (14%) of Childers and 9/25 (36%) of Turpin measurements, are newly-generated by this research.

clearly duplicated. At the same time, there is a concentration of enriched individuals among the populations of the upper Ohio Valley. Within the Middle Valley, groups along the main trench of the Ohio tend to be more enriched than those along the tributaries.

In Figure 66, the isolines indicate a generally decreased level of maize consumption in the Middle Valley during the late Late Prehistoric period. Southwest Ohio continues to exhibit somewhat depleted $\delta^{13}C$ values, relative to the rest of the region. The single individual from Barker's Bottom, also relatively

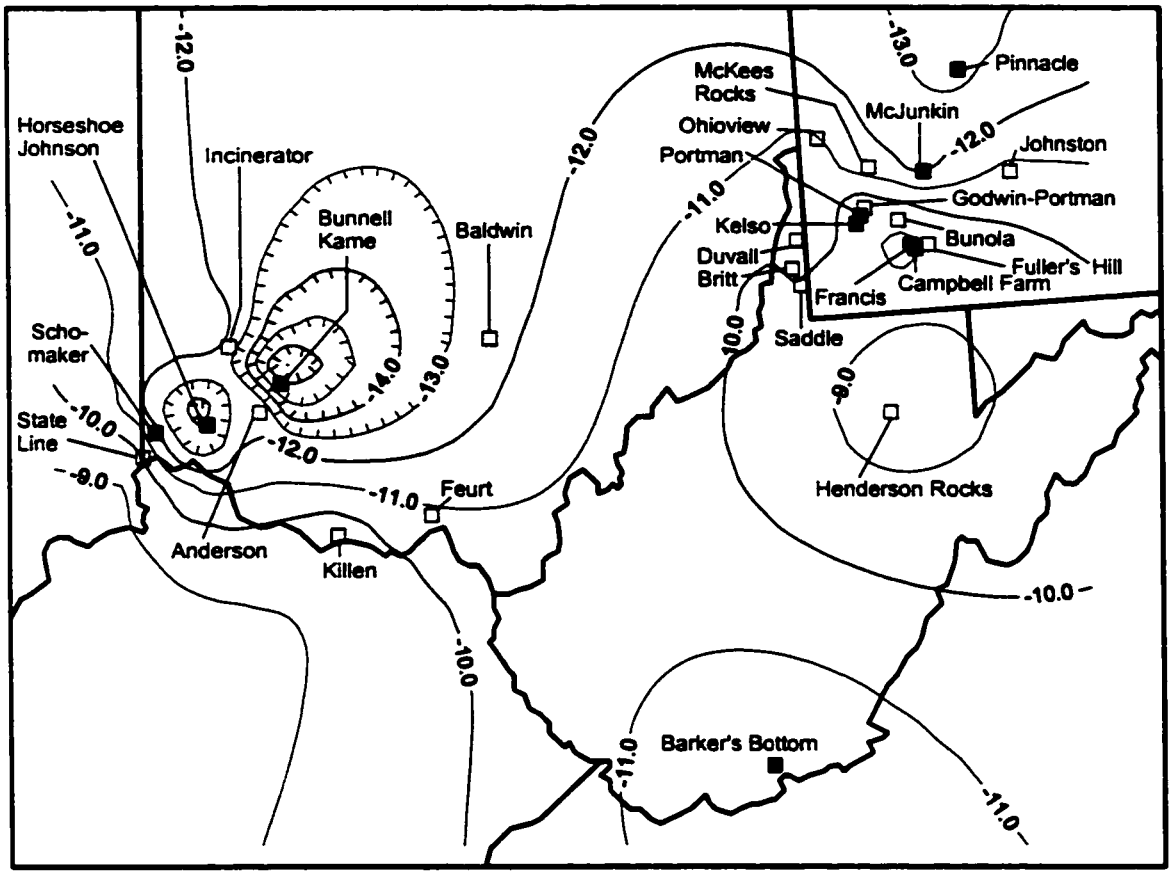


Figure 65. **Geographic distribution of $\delta^{13}C$ values from middle Late Prehistoric deposits.** Hollow symbols indicate means for locales with more than two individuals analyzed; solid symbols indicate individual values. All data, except Incinerator, Barker's Bottom, Henderson Rocks, Duvall, Britt Bottom and 20/22 (91%) of Feurt measurements, are newly-generated by this research.

depleted, presents a significant amount of influence on the pattern of isolines. Finally, I note that the populations of the Upper Valley continue to show increasingly enriched values relative to the rest of the region. It is apparent that this map and the preceding ones are much influenced by sample numbers, so it should be anticipated that the particulars will certainly change as future work generates more data. The main trends, i.e., early dominance at the margins and persistent variability, should prove stable, however.

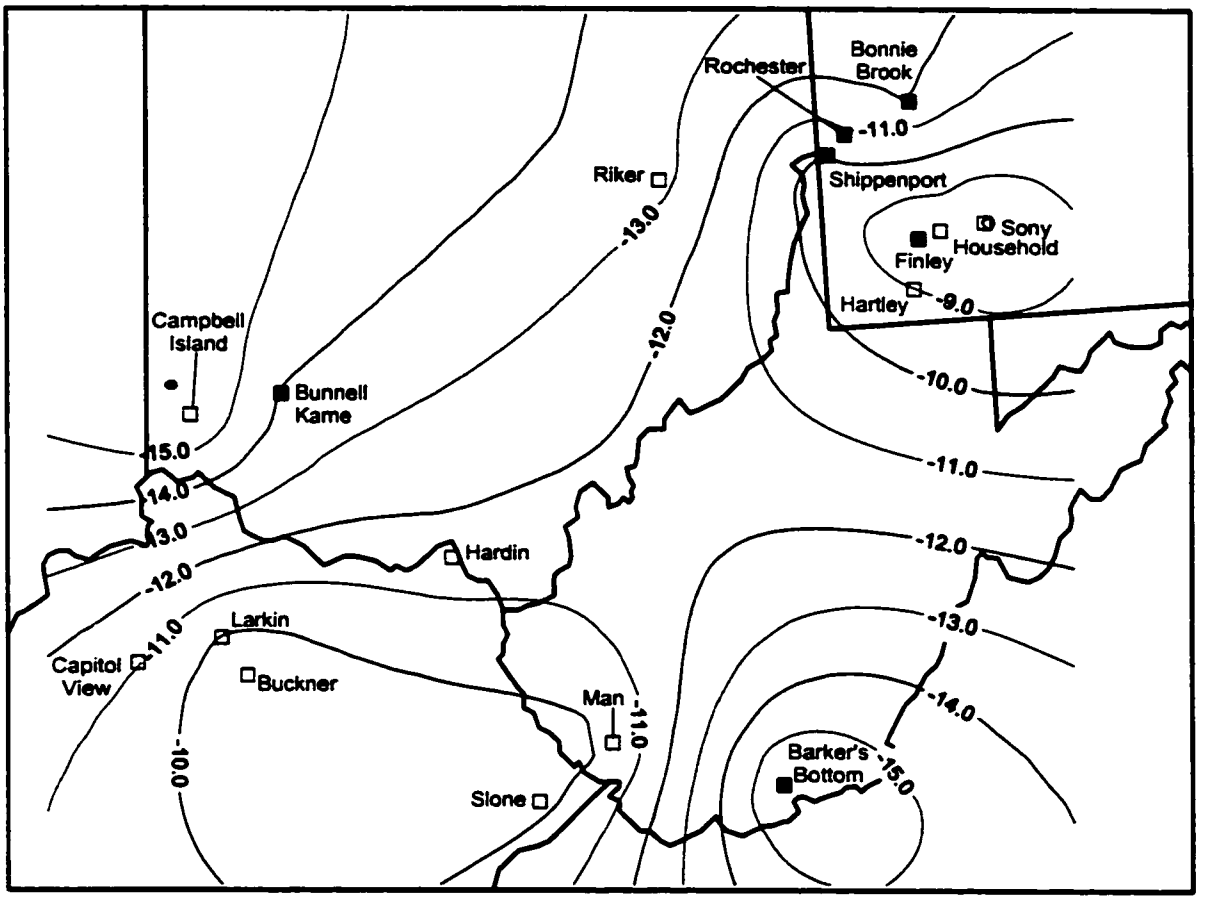


Figure 66. **Geographic distribution of $\delta^{13}C$ values from late Late Prehistoric deposits.** Hollow symbols indicate means for locales with more than two individuals analyzed; solid symbols indicate individual values. Data for all locales in Ohio, Pennsylvania and 2/17 (12%) of Slone measurements are newly-generated by this research.

That the Late Prehistoric populations of the Upper Valley tend to be more enriched than those of the Middle Valley has been suggested before (Greenlee 1991). A *t*-test comparing $\delta^{13}C$ values (for samples later than A.D. 900 and assuming unequal variances) between the Upper and Middle Valleys indicates that individuals of the Upper Valley have significantly greater isotope ratios than those of the Middle Valley ($t = -8.647$; $p < .001$). Even when all relatively-depleted individuals (< -15 ‰) are removed from the samples, a move which

disproportionately affects the Middle Valley, individuals of the Upper Valley are still more positive than those of the Middle Valley ($t = -7.009$; $p < .001$).

SUMMARY

Following an evaluation of "collagen" integrity, newly-generated stable carbon isotope ratios for 251 archaeological human bones from the middle and upper Ohio Valley were presented. These data were combined with previously-collected isotope measurements from the region to examine the timing, tempo and structure of dietary change associated with the occurrence of maize-dominated diets. Clearly, there is no evidence to suggest that dietary change associated with the spread of maize farming was a phenomenon that gradually swept up the Ohio River and its tributaries. The change, when and where it occurred, appears to have been remarkably abrupt – there was nothing gradual about it. The earliest evidence of significant maize consumption, spotty at best, occurs at the margins of the region. Even once maize was well-established across the region, in southwest Ohio, a population of individuals who consumed significantly less or even no maize was maintained throughout the temporal sequence. In contrast, the populations of the upper Ohio Valley, despite their reputation as "backwater cousins" of the Fort Ancient in the Middle Valley, evidence greater commitment to maize consumption.

Taken together, these data indicate considerable variation in the pathways of dietary change associated with maize farming; i.e., it happened differently in different parts of the region. That is a good thing, for as Wood (1994a:46) so succinctly put it, "Only differences in effects reveal something about the differential contribution of causes." In the next four chapters, I evaluate the evidence for four very different causes that have been suggested to account for different aspects of prehistoric subsistence variation in the Eastern Woodlands.

CHAPTER SIX: ENVIRONMENTAL VARIATION AND CLIMATIC CHANGE

This chapter evaluates the role of climatic change as a parameter in explaining variation in the records of subsistence and dietary change. Before getting down to the business of arraying the evidence for climatic change against the archaeological record, however, some background information about the physiography, ecology and modern climate of the region is required. This is because a given episode of climatic change will have variable impacts upon subsistence systems depending on the direction and magnitude of the change, the geographic and physiographic setting of the exploited catchments, the growing requirements of the resources exploited, and the natures of the subsistence systems themselves. In addition, it is possible that some of the geographic variation seen in the isotopic record may be a function of environmental factors.

PHYSIOGRAPHY

Reflecting differences in age and underlying geological structure, the study region is comprised of portions of three physiographic provinces (Figure 67). The character of the landscape throughout the study region is highly variable, ranging from broad floodplains to constricted bottoms along tributary streams, from rolling uplands to narrow, snaking ridges, and from mild to substantial topographic relief. Elevational cross-sections, derived from 1:100,000-scale metric topographic maps, illustrate considerable variation in topography (Figure 68).

The bulk of the study area lies within the Appalachian Plateaus province (Fenneman 1938; Hunt 1974). Structural and erosional variation throughout the province provide the basis for further subdivisions such as the Glaciated Allegheny Plateau, the Unglaciated Allegheny Plateau and the Allegheny Mountains sections shown in Figure 67. Its broad plateaus and narrow, meandering ridges between deeply entrenched streams are a consequence of

differential erosion of nearly horizontal sedimentary strata (primarily sandstones, conglomerates, shales and limestones) deposited in a Paleozoic geosyncline. The sandstones and conglomerates are most resistant to weathering (Pirkle and Yoho 1977); thus, when at the surface, they protect the underlying sediments, resulting in the formation of considerable topographic relief (Figures 68a and b). Local relief varies tremendously, on the order of 60 – 90 m in the western portion and 340 m near the eastern edge (Fenneman 1938).

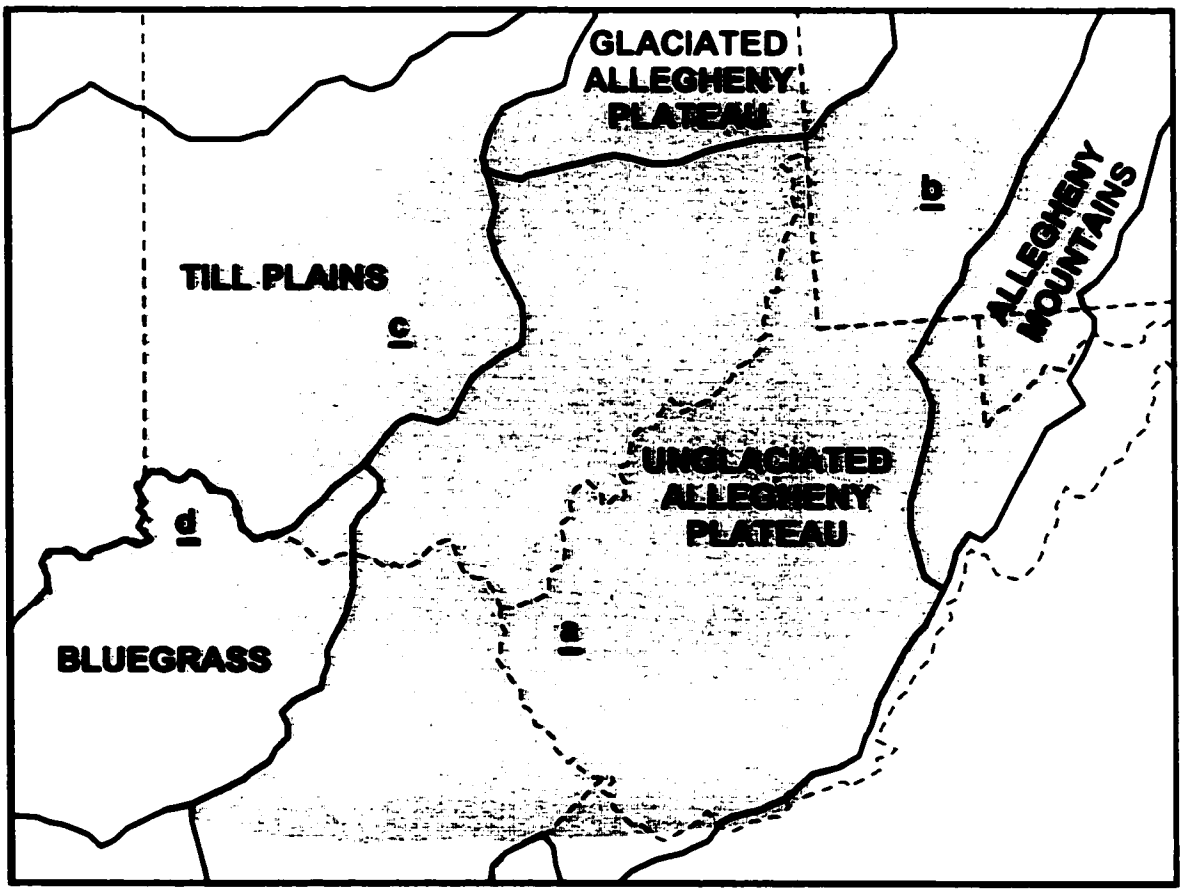


Figure 67. **Relevant physiographic regions in the study area.** After Fenneman (1938) and Hunt (1974). a, b, c, and d indicate the location of cross-sectional transects shown in Figure 68.

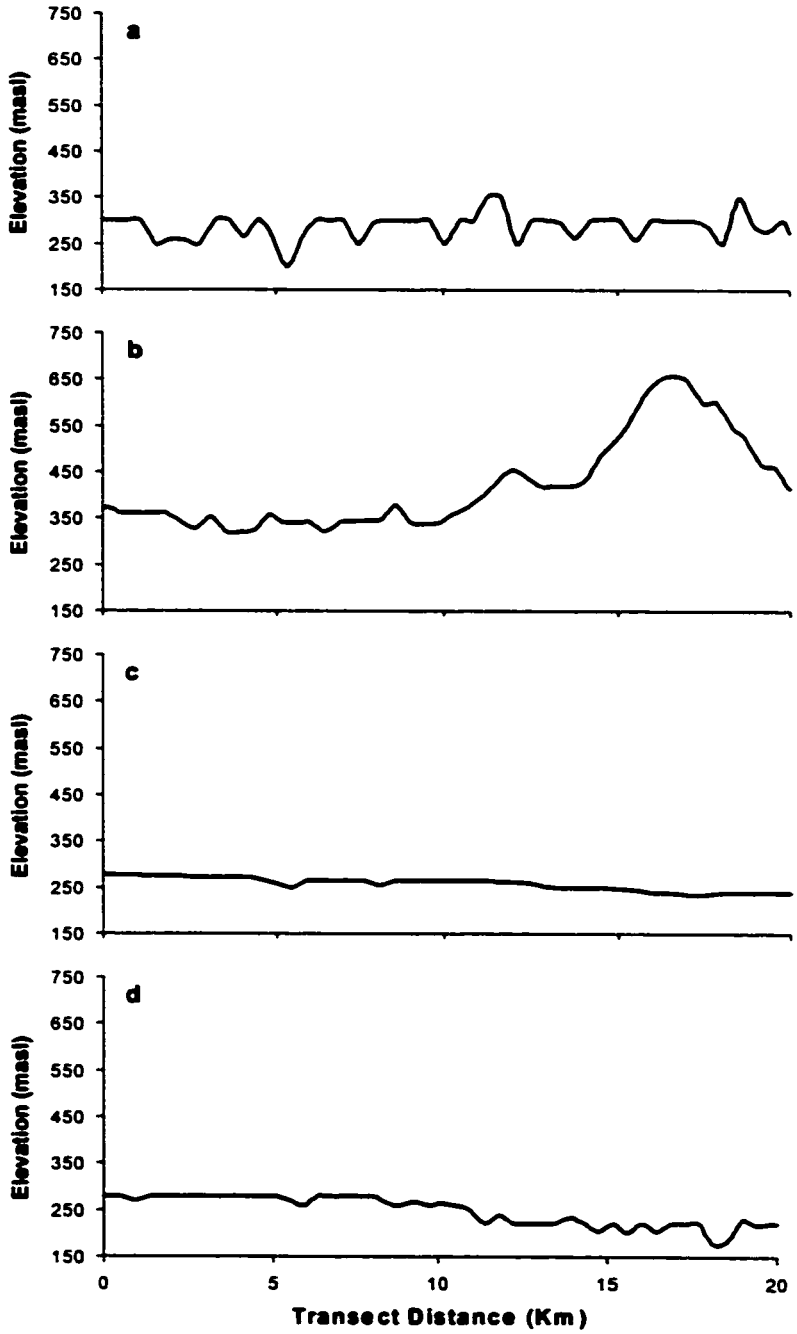


Figure 68. Elevational cross-sections illustrating variation in physiography across the study region.

The Till Plains section (Figure 67) of the Central Lowland province (Fenneman 1938; Hunt 1974) consists of broad, level uplands separated by steep-sided valleys with broad floodplains. Local relief is slight (Figure 68c), typically much less than 30 m. This is due to minimal erosion of glacial deposits which cover the underlying bedrock formations, themselves nearly horizontal sedimentary deposits (Pirkle and Yoho 1977). Relief is most pronounced to the South, a result of greater time for drainage system establishment in the mostly pre-Wisconsinan till. While a current map of this physiographic section shows numerous lakes, they are manmade; although portions of the section were quite marshy, there are few natural lakes or ponds.

The Kentucky Bluegrass (a.k.a. Lexington Plain) of the Interior Low Plateaus province (Fenneman 1938; Hunt 1974) is below the southern limit of Pleistocene glaciation and west of the Allegheny Plateau (Figure 67). While the geological substrate of the province is largely composed of sedimentary sandstones, shales and limestones, the Bluegrass region itself is underlain predominantly by limestone deposits. Located within a topographic basin, the rolling uplands of this mildly karstic region (Figure 68d) are dissected by entrenched, meandering streams and pocked by sinkholes (Pirkle and Yoho 1977).

PHYSIOGRAPHY AND ISOTOPIC DIET

Physiographic provinces are generally considered too imprecise to be of much use in archaeological research beyond providing background information about the prehistoric landscapes on which people lived and worked. Even so, I note an apparent physiographic pattern in the distribution of Late Prehistoric relatively depleted (< -15 ‰) individuals. With few exceptions (Baum, Childers and Barker's Bottom), those depleted individuals of the Middle Valley are restricted to the Till Plains section of the Central Lowlands province (Figure 69). Later, the role of physiography in structuring ecological development in the study region is

considered and hypotheses that might account for this nonrandom distribution of relatively depleted individuals are evaluated.

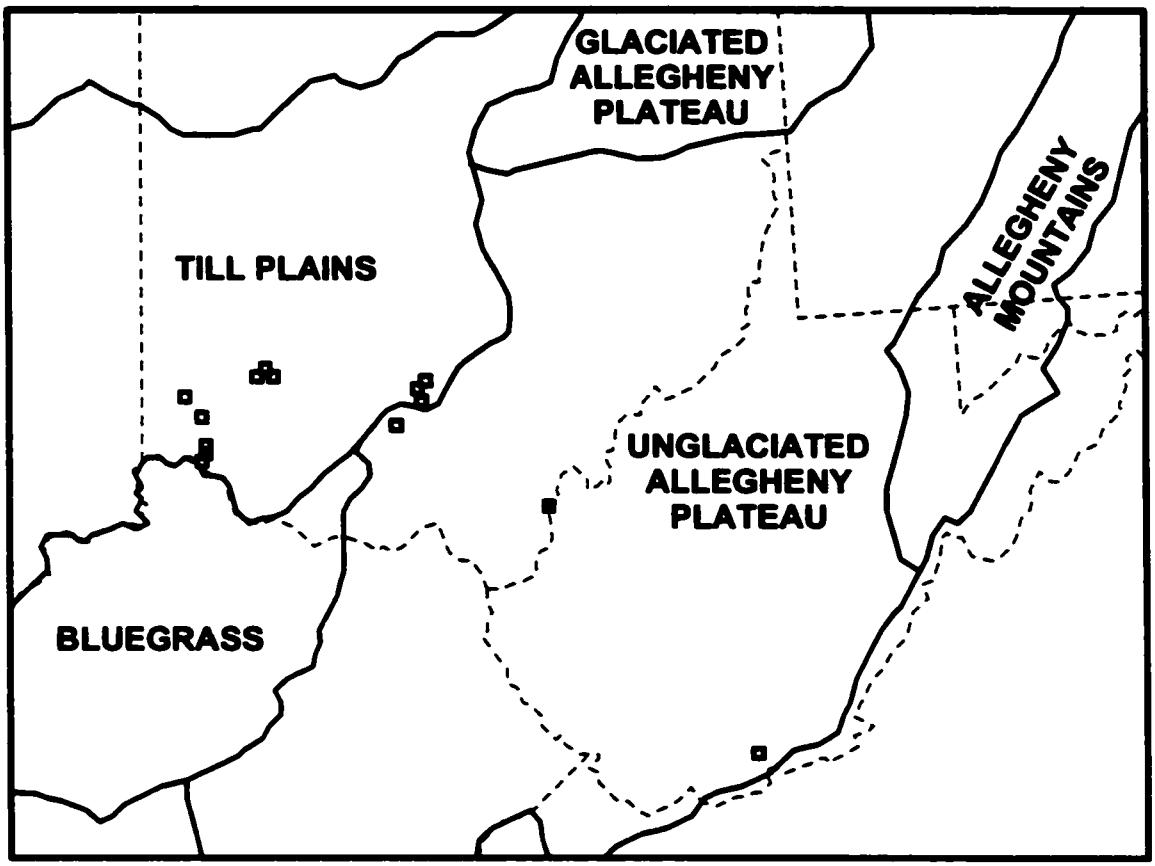


Figure 69. **Distribution of post-A.D. 850 isotopically-depleted individuals with respect to physiographic province.**

On a local level, physiography is important to human populations in several ways (e.g., it impacts local climate and ecology, the amount of land available for settlement and cultivation, and the availability of defensive situations). We might, for example, expect to see systematic differences in the subsistence systems of populations living in bottomland and upland settings. Certainly, the availability and economic return of aquatic resources varies among bottoms and uplands; vertebrate remains from Ohio Valley archaeofaunal assemblages reflect differential exploitation of aquatic resources between the two settings (Greenlee 1994). The

aquatic resource index, which expresses the proportion of aquatic to terrestrial resources for each assemblage[33] as

$$\Sigma \text{ Aquatic Taxa} / \Sigma \text{ (Aquatic Taxa + Terrestrial Taxa)},$$

is shown in Figure 70 for upland and bottom settings in the Upper and Middle Valleys. A Levene's test for homogeneity of variance indicates that the variance differs significantly between upland and bottom assemblages ($F = 9.567$; $p = .003$); a Mann-Whitney test indicates that exploitation of aquatic resources in the uplands differed significantly from that in the bottoms ($U = 130.500$; $p = .002$).

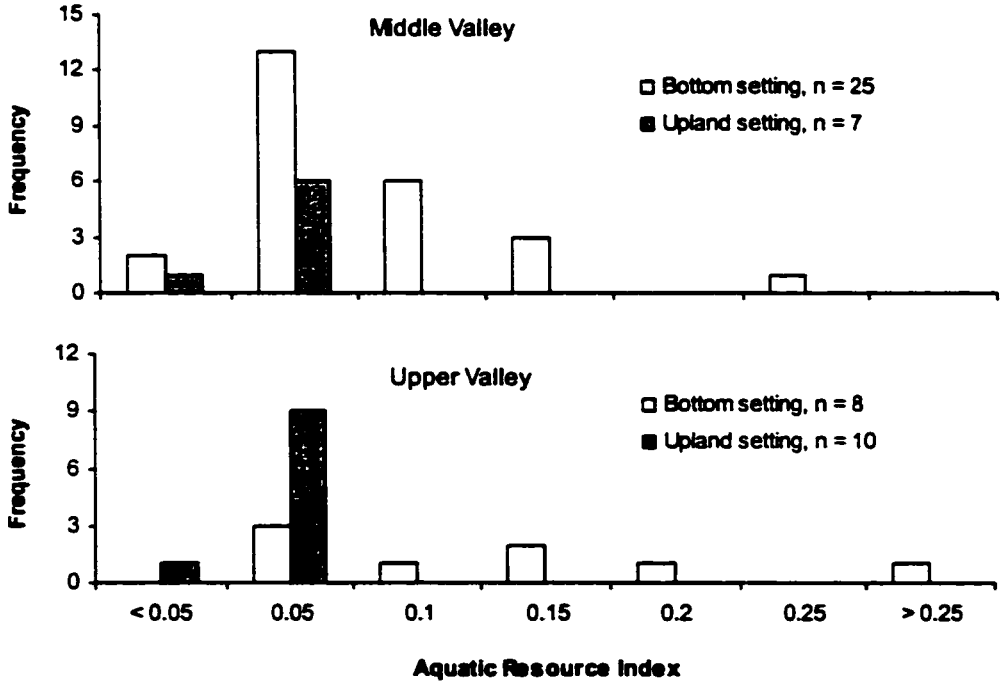


Figure 70. **Aquatic resource index for upland and bottom assemblages in the middle and upper Ohio River valley.** Data are presented in Appendix B.

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[33] For this analysis, fish, reptiles and amphibians (otherwise removed to minimize bias due to different collection techniques) were included in the assemblage counts. The aquatic index does not vary according to preservation ($\chi^2 = 5.922$; $p = 0.115$), collection technique ($U = 256.500$; $p = .384$) or NISP ($\rho = -.049$; $p = .737$).

Prehistoric commitment to maize farming may have differed between upland and bottomland settings as well, reflecting differences in ecological diversity, soil properties and amount of arable land in the surrounding catchments. Based on their analyses of $\delta^{13}C$ values and dental attributes, respectively, both Farrow (1986) and Sciulli and Carlisle (1977) suggested that Upper Ohio Valley populations residing in bottoms may have consumed more maize than those living in the uplands. Their intuitive logic is that because bottomland soils are deeper and richer than upland soils, net maize yields should have been relatively greater and maize should have contributed relatively greater amounts to bottomland than upland diets. Subsequent analyses have failed to identify statistically significant differences in maize consumption between upland and bottomland populations of the Upper Ohio Valley (Greenlee 1990; Sciulli 1995).

The subsistence systems of prehistoric groups living in different settings in the Ohio Valley appear to vary inversely with the amount of arable land in their surrounding catchments (Greenlee 1990). Individuals living in broad valleys tended to be less enriched than those living in narrow valleys and on ridged uplands. The former situations are generally characterized by greater ecological diversity and richness than the latter; in other words, broad valley situations offered abundant wild resource alternatives to maize that narrow valley and upland situations could not. Thus, maize should have contributed more to the diets of populations living in the latter situations (uplands and narrow valleys). This hypothesis is supported by Broida's (1984) finding that a population in a narrow valley setting was more enriched than one in a broad valley situation.

With this in mind, I turn to the isotopic record of the Upper Ohio Valley to determine if physiographic setting did, in fact, influence maize consumption among populations there (Figure 71). In addition to using a larger sample and more detailed physiographic classes (uplands, broad bottoms and narrow bottoms) than used previously, the implication of my hypothesis is opposite

to that proposed earlier by Farrow and Sciulli and Schneider – upland and narrow bottom populations should have a greater dietary commitment to maize than those situated in broad bottoms. Because the number of individuals with $\delta^{13}C$ data from narrow bottoms is so small (n = 5), they are pooled with individuals from upland situations; this decision is supported by a *t* test, which indicates that the mean $\delta^{13}C$ values for individuals from upland (mean ± 1 sd = -9.389 ± 1.420 ‰) and narrow bottom (mean ± 1 sd = -8.968 ± 0.484 ‰) situations do not differ significantly (t = -1.425; p = .178). In a one-tailed *t*-test to assess whether the mean $\delta^{13}C$ value of individuals from broad bottoms is greater than, or equal to, that from uplands/narrow bottoms, the null hypothesis is rejected (t = 1.960; p = .028).

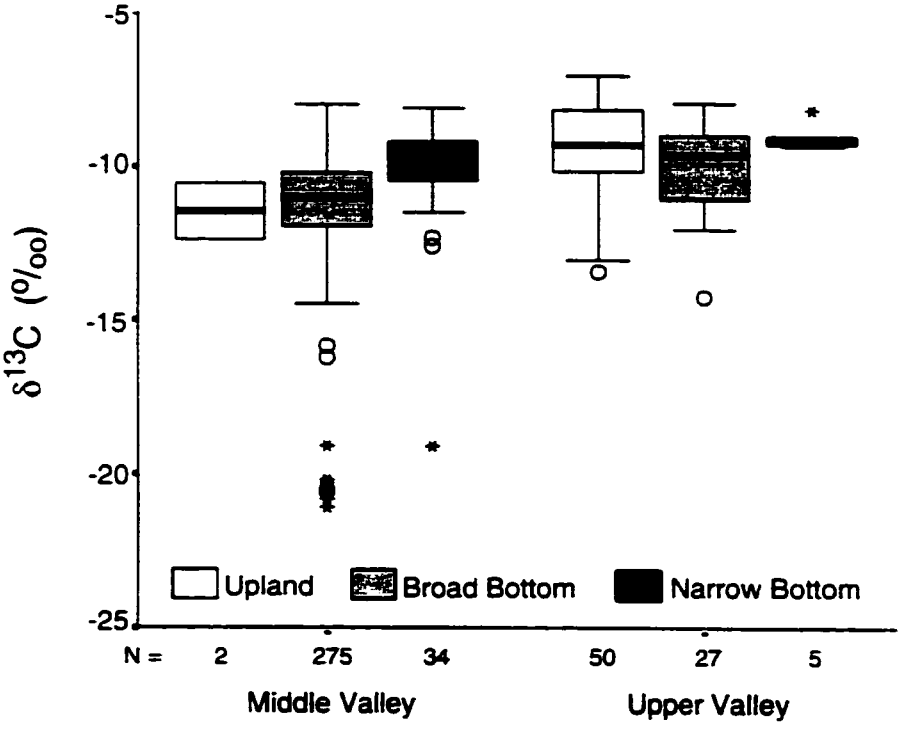


Figure 71. **Stable carbon isotope ratios in different physiographic situations in the middle and upper Ohio Valleys.** The Os indicate outliers (> 1.5 box lengths); the *s indicate extreme values (> 3 box lengths).

Upper Valley populations living in broad bottoms consumed significantly *less* maize (mean ± 1 sd = -9.996 ± 1.419 ‰) than those in the other two physiographic settings (mean ± 1 sd = -9.351 ± 1.365 ‰).

$\delta^{13}C$ values for individuals occupying different physiographic settings in the Middle Valley are also compared in Figure 71. Because few Late Prehistoric individuals with $\delta^{13}C$ data occupied upland settings (n = 2), this statistical analysis is limited to broad vs. narrow valley settings. The mean $\delta^{13}C$ values of individuals from the two physiographic settings meet expectations of the hypothesis, with those from broad bottoms (mean ± 1 sd = -11.601 ± 2.741 ‰) being less enriched than those from narrow ones (mean ± 1 sd = -10.145 ± 1.874 ‰). The difference is statistically significant (t = -3.010; p = .003). Even when all $\delta^{13}C$ values ≤ -15 ‰ are removed, the difference remains significant (t = -4.029; p < .001). The notion that maize consumption was influenced prehistorically by physiographic setting is supported in a nonintuitive way.

ECOLOGY

There are two opposing images of the "virgin" forest[34] of the Eastern Woodlands: a forest so open that one could drive a stagecoach from the shores of the Atlantic ocean to St. Louis without clearing a road versus a forest so thick and unbroken that a squirrel could travel from Maine to Louisiana without touching a foot to the ground (Pyne 1982). Although we can say with confidence that reality lies on a continuum somewhere between the two, exactly where on that continuum varies with the location and the data available. Below, I first seek to establish the

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[34] Although the term "virgin" has been used historically to describe the forests of the East prior to Euroamerican disturbance, it is not really an appropriate adjective. Amerindians inhabited eastern North America for thousands of years prior to the arrival of Euroamericans, thus the ecology can hardly be considered untouched by human activities. The impact of the former populations was certainly less apparent than that of the latter ones, however.

nature of the ecological setting in the region prior to Euroamerican influence. Next, I consider the potential impact of ecology on subsistence variation. Finally, I examine evidence for Amerindian impacts upon that ecology.

The eastern deciduous forest is, with the possible exception of forests in southeastern China, the most complex on Earth (Hunt 1974). Containing over 1000 tree species, the forest also supports diverse shrub and herb communities. Unfortunately for ecologists, the activities of Euroamerican colonists (logging, farming, and introduction of exotic plants, animals and diseases) altered radically the composition and structure of the flora and fauna of the eastern deciduous biome before much of it could be adequately described (Barbour and Christenson 1993; Braun 1964; Trautman 1977). What Küchler (1964) defines as the "real vegetation," the vegetation present at the time of observation, has an unknown relationship to the "potential natural vegetation," which is what the vegetation *should* look like if those alterations had not occurred. Only isolated fragments of primary forest remain throughout much of the East and, in some areas (e.g., the Inner Bluegrass), there are few plots of vegetation unaltered by Euroamerican activities.

Ecological knowledge of the region at Contact is based largely on reconstructions derived from study of these isolated forest remnants, in conjunction with historical descriptions by early explorers (Ketchum 1864; Michaux 1904a, 1904b) and United States General Land Office (USGLO) surveyors. USGLO notes, generated during the original survey of public lands authorized in 1785, contain locations and identifications of witness and bearing trees, as well as general descriptions of the landscape prior to widespread European settlement and disturbance (Bourdo 1956; Gordon 1969; Potzger et al. 1956; Sears 1921, 1926a; Whitney 1990). Using these sources, ecologists (e.g., Barbour and Christenson 1993; Braun 1964; CERNITT 1999; Greller 1988; Küchler 1964) have pieced together a picture of the eastern biome prior to Euroamerican influence. They have identified three or four primary forest associations in the study region; not

surprisingly, the forests correlate broadly with physiography. Following Braun (1964), I describe four associations: the mixed mesophytic, the hemlock-white pine-northern hardwood, the beech-maple, and the western mesophytic forests (Figure 74).

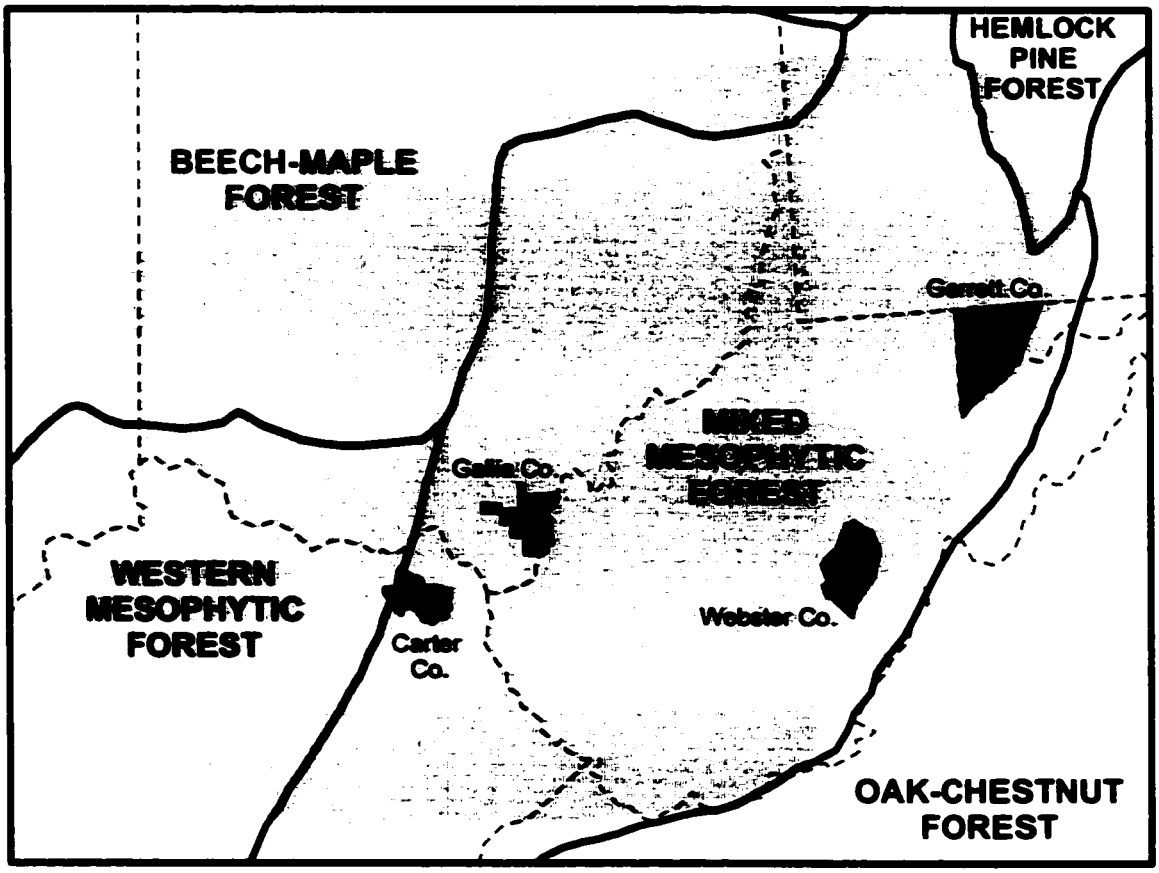


Figure 72. **Forest associations in the study area.** From Braun (1964). Vegetation data from indicated counties (dark gray) are presented in Figure 73.

The mixed mesophytic forest ranges over the unglaciated portion of the Appalachian Plateaus province. The canopy is often dominated by taxa such as beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), tulip tree (*Liriodendron tulipifera*), buckeye (*Aesculus octandra*), and species of basswood (*Tilia* spp.) and oak (*Quercus* spp.); many other trees are present in the canopy and subcanopy.

Topography, elevation and soil texture are influential in determining which combination of canopy trees will dominate at any particular location.

That the mixed mesophytic forest is characterized by great diversity is illustrated in Figures 73 and 74. In Figure 73, which presents the five dominant trees comprising the mixed mesophytic canopy at locales in four different counties (Figure 72), different combinations of taxa dominate at each locale and no taxon is among the five most dominant for all locales. In Figure 74, which compares the dominant trees in different topographic settings at one locale, one taxon, white oak (*Quercus alba*), is found in all four settings and it dominates in three of those four settings; *Liriodendron tulipifera* dominates the fourth setting. Although all forest

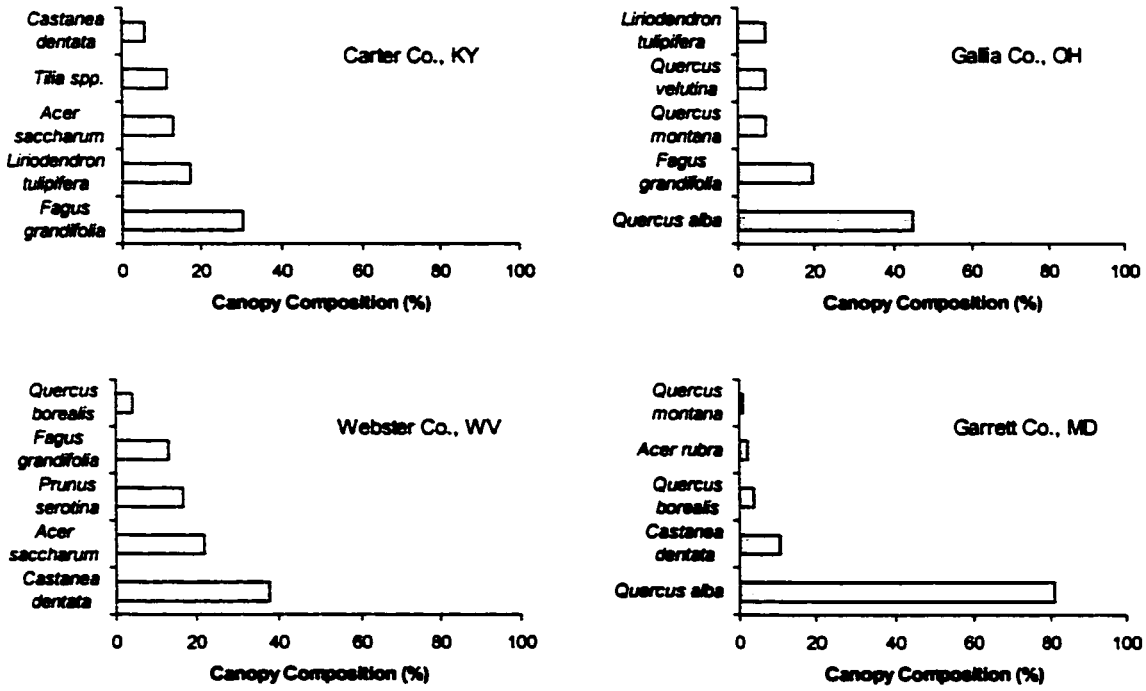


Figure 73. **Variation in canopy composition of mixed mesophytic forest communities from different places in the study region.** Locations are shown in Figure 72. Data from Braun (1964:78, 79, 97, 105).

associations exhibit this sort of variation in composition to some degree, the complexity of other associations is not comparable to that of the mixed mesophytic association. Thus, the mixed mesophytic forest is best viewed as a complex mosaic of forests, the actual composition varying from one location to another depending upon local environmental conditions.

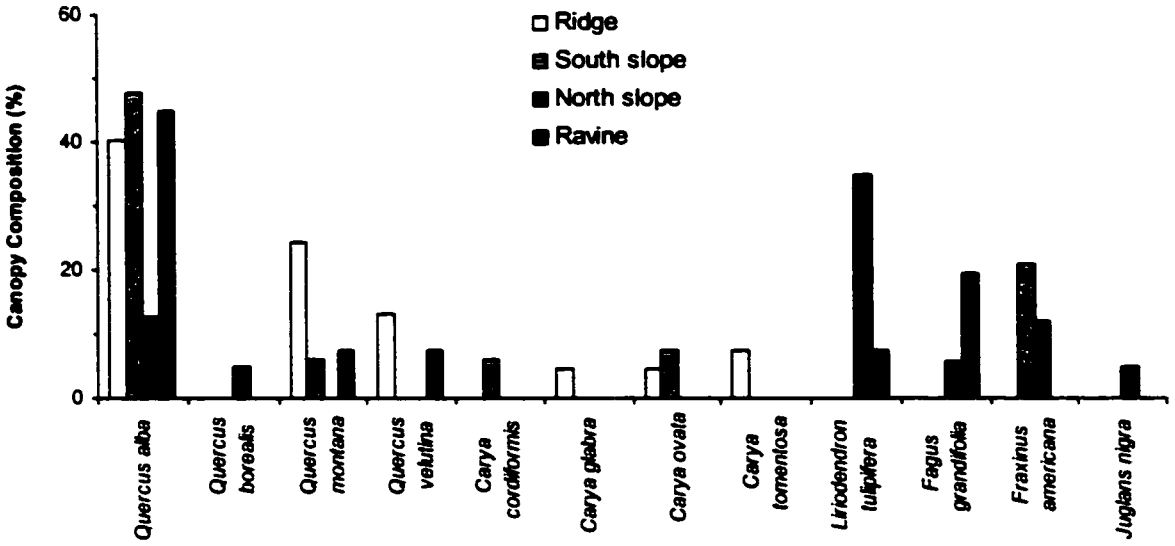


Figure 74. **Forest composition of different topographic settings in Gallia Co., OH.** Data from Braun (1964:97).

The hemlock-white pine-northern hardwoods forest extends across the Great Lakes area, following the Allegheny Mountains southward into western Pennsylvania (Braun 1964). It is considered a transitional association between the hardwoods of the mixed mesophytic forest to the south and the boreal forest to the north (Barbour and Christenson 1993). That portion of the association that is included in the study area is highly variable, with groves dominated by hemlock-beech and, to a lesser extent, hemlock-white pine associations. Various hardwoods seen in the mixed mesophytic forests further south are present, as well.

The beech-maple forest covering the Till Plains is, as the name implies, dominated by *Fagus grandifolia* and *Acer saccharum* (Braun 1964). The

forest also displays variation with topography and drainage; wetter sites may contain abundant *Fraxinus* spp., *Ulmus* spp., and *Acer rubrum*, while drier locales may be dominated by species of *Quercus* and *Carya* (Barbour and Christenson 1993; Greller 1988). Küchler (1964) notes the significant presence of bluestem prairie, which is a dense, tall grassland dominated by big and little bluestem (*Andropogon gerardi* and *A. scoparius*), switchgrass (*Panicum virgatum*) and Indian grass (*Sorghastrum nutans*), in the west-central portion of Ohio bordering on the beech-maple and western mesophytic forests.

Reconstructions of Ohio vegetation based on historic documents (Gordon 1969; Sears 1926b) show a significant presence of treeless areas within the state. These treeless areas, loosely referred to as "prairies," are largely restricted to parts of the state that were formerly glaciated and within the beech-maple association. Although in neither case is the fit perfect, boundaries around such things as forest associations being quite imprecise, the spatial correlation is quite close. Following Sears' (1926b) reconstruction, Figure 75 maps the distribution of wet areas (swamps, bogs and wet prairies), dry areas (dry prairies), and areas (prairies and barrens) that were not distinguished as either wet or dry. Of the 110 locations identified as either wet or dry, 98% were wet. If that frequency could be applied to the locations of undocumented wetness, the amount of swampy, marshy land in western and central Ohio would be quite considerable. Although some of these "prairies" may be due to Amerindian activities, Sears notes that their nearly exclusive association with glaciated landscapes suggests they are primarily "natural" phenomena. That significant wetlands existed is also clear in Gordon's later reconstruction of the natural vegetation of Ohio (Gordon 1966), where elm-ash swamp forests comprise a significant proportion of the vegetation in the beech-maple forest association, particularly in southwest Ohio.

The western mesophytic forest, covering much of the Interior Low Plateau, is considered a transitional vegetation between the rich mixed mesophytic

forests to the east and the oak and oak-hickory dominated forests and prairies to the west (Braun 1964). In general, as one moves from east to west across this region, the vegetation becomes less rich, appearing less like a mixed mesophytic forest and more like an oak-dominated one.

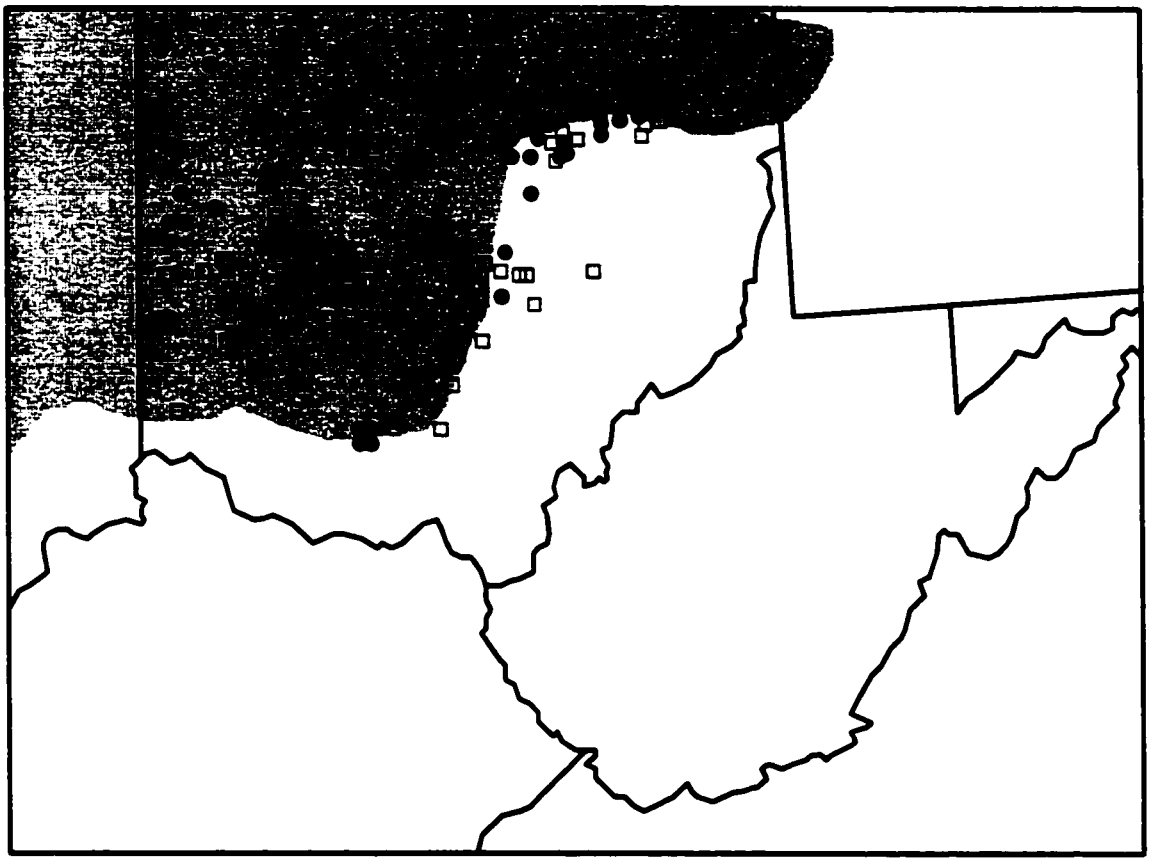


Figure 75. **Distribution of treeless areas with respect to the beech-maple association.** Markers indicate locations of bogs/swamps/wet prairies (●), dry prairies (◇) and wet or dry prairies/barrens (□) relative to the beech-maple forest (shaded area). Data from Sears (1926b).

Like the vegetation, the fauna of the study area has also witnessed considerable alteration by Euroamerican activities and must be reconstructed from spotty historic records. Most notable changes include the extinction of the passenger pigeon (*Ectopictes migratorius*) and the local extirpation of several species including the bison (*Bison bison*), black bear (*Ursus americanus*), river otter

(*Lontra canadensis*), gray wolf (*Canis lupus*), mountain lion (*Felis concolor*), marten (*Martes americana*) and fisher (*Martes pennanti*). More subtle changes in the distribution and abundance of other fauna resulted from a variety of factors, including changes in the availability of favorable habitats (for both food resources and protective cover), predator and competitor population levels, and human hunting practices (Trautman 1977).

ECOLOGY AND PREHISTORIC SUBSISTENCE

Chapter Two shows how the frequency of elk and bear remains in Ohio Valley faunal assemblages appears to correspond to geographic variation in local environmental circumstances; $\delta^{13}C$ values are also shown to vary geographically. For comparative purposes, Figure 76 shows the pattern of isolines that describe spatial variation in $\delta^{13}C$ values from middle Late Prehistoric-aged populations against the formerly glaciated portion of the study area. That time period was chosen because the number of data points is relatively large and because geographic variation reflecting the spread of maize farming is less likely. The isotope data from the early and late Late Prehistoric periods show similar patterns with respect to the formerly glaciated areas, suggesting that the distribution shown here is not a random one. As further evidence, a *t*-test indicates that significant differences exist at $\alpha = .05$ in mean $\delta^{13}C$ values of Late Prehistoric individuals between (formerly) glaciated (mean ± 1 sd = -11.463 ± 2.700 ‰) and unglaciated (mean ± 1 sd = -10.629 ± 2.046 ‰) portions of the Ohio Valley ($t = -3.219$; $p = .001$).

The spatial correlation between relatively low $\delta^{13}C$ values and (formerly) glaciated areas in Ohio suggests selective conditions may have differed geographically. To establish why individuals in this area maintained a diet different from the diets of individuals living elsewhere in the study region requires that we consider how this area of Ohio differs from the rest of the study area and how those differences might contribute to dietary variation. A few possible reasons come to mind: (1) soils were not as suitable for maize production as in other areas;



Figure 76. **Map showing the relationship between $\delta^{13}C$ values during the middle Late Prehistoric period (isolines) and formerly glaciated areas (shaded) of the study region.**

(2) climatic conditions were less amenable than other areas with respect to the growing requirements for prehistoric races of maize; or (3) wild resources of the area were so predictable and abundant that populations were supported with smaller contributions by maize to the overall diet. Since little is known about prehistoric farming techniques[35] and maize growing requirements, there is little direct evidence

[35] In some parts of the Eastern Woodlands, researchers have argued that Amerindians relied on permanent field agriculture based on ridged, raised or mounded beds (Doolittle 1992; Gallagher 1989; Riley 1987). Little is actually known about the cultivation techniques employed by Ohio Valley maize farmers and, in the absence of physical evidence for prepared fields, I assume here that some manner of swidden farming was employed.

by which to evaluate those hypotheses. I consider them to the degree possible with the data available.

What about the quality of soils available for maize farming? Nass (1988) examined the ability of soils in southwest Ohio to support Late Prehistoric farming populations there. He tabulated the relative proportion of different classes of soils (based on drainage, texture and slope) in 3.0 Km catchments around each of several settlements. When viewed in light of assumptions about the productivity of the farming systems, the caloric intake of the communities, and the amount of land necessary to sustain those communities under those conditions, he concluded that there was sufficient good quality soil surrounding each settlement to more than support their populations. More important, since we are ignorant of prehistoric maize requirements, is how the soils of southwest and central Ohio compare to those of other parts of the study region.

Because they are strongly influenced by physiography and parent materials, soils of the glaciated Till Plains might be expected to differ from those elsewhere in the study region. Appendix H details my examination of soils in 2.5 Km radius catchments surrounding fifteen archaeological locales for which there are isotope data. The proportion of soils presumably well-suited to maize cultivation in catchments surrounding Till Plains locales was not found to be less than that found in catchments elsewhere in the study region. Kennedy (2000) goes further to conclude, based on his analysis of soils surrounding Late Prehistoric sites in the Middle Valley, that the most fertile soils are found in the greatest abundances in southern Ohio catchments. Thus, based on the available data, the geographic patterning in $\delta^{13}C$ values cannot simply be chalked up intuitively to differences in the availability of "good" soils.

With respect to the impact of climatic conditions, again we do not know the growing requirements for the races of maize grown prehistorically in the Ohio Valley. It seems unlikely, though, that they were so different from modern

Northern Flint varieties as to make climatic conditions in southwest and central Ohio significantly less suitable for growing maize than conditions in central Kentucky or southwest Pennsylvania. This area, if anything, tends to be intermediate to those other areas with respect to most climatic variables that influence plant productivity. There is, however, one exception: historically, the severity and relative frequency of summer (June, July, August) drought conditions are greater in western and central Ohio than elsewhere in the study region.

Although environmental conditions throughout the growth cycle of maize impact the plant in many parts of the Eastern Woodlands, conditions during the months of June, July and August are particularly important to determining crop yields. Moisture stress created by high temperatures and/or low precipitation during those months, when tassling, silking, pollination and grain-filling occurs, can severely reduce crop yields (Shaw 1983). Consequently, farmers of southwest and central Ohio may have experienced reduced crop yields due to drought more frequently and to a greater degree than in other parts of the region. Under such conditions, individuals with broader (more generalized) diets and less commitment to maize (cf. Halstead and O'Shea 1989b; Larson et al. 1996) would have had an advantage over individuals more reliant upon maize. If summer droughts were a factor, their impact should be mitigated during cooler and/or wetter climatic episodes; this scenario will be evaluated below in my consideration of climatic change.

Ethnographic descriptions of swidden farming systems consistently remark on how they avoid grassland associations, whether of natural or cultural origin (Carneiro 1983; Conklin 1957; Harris 1972; Moran 1983; Rappaport 1971). Clearing and farming grasslands is impossible for swidden farmers using fire alone for clearance; there is insufficient fuel to destroy the sod and to kill weed and tree seeds. Thus, there is reason why crops produced by swidden farming may not have

dominated subsistence systems where a significant fraction of the surrounding vegetation was grass.

It is also difficult to farm bogs, marshes and swamps. Although it is practically impossible to establish the amount of land in "prairies" surrounding any particular place (many of them having been destroyed quite early by Euroamerican activities), recall that Sears (1926b) had identified a significant presence of wet and dry "prairies" in the beech-maple forest that covered formerly-glaciated Ohio. As Figure 77 shows, there is some association between the presence of "prairies" and the distribution of low $\delta^{13}C$ values. Although they occur rarely in Ohio Valley archaeofaunal assemblages, taxa restricted to prairie/grassland habitats (Figure 77) are found in four assemblages from this area. That these taxa also are found in a few assemblages elsewhere in the region may reflect the creation of anthropogenic grasslands on a local scale through burning or swidden farming (e.g., Conklin 1957; Rappaport 1971).

Assuming that the "prairies," wet or dry, were not farmed, those habitats still may have provided significant resources for local subsistence systems. Floristic lists for the different "prairie" types often contain several taxa identified ethnographically as edible plants (Fernald and Kinsey 1943; Gillespie 1959; Green 1984; Kindscher 1987; Reidhead 1984); fleshy parts (e.g., bulbs, roots, flowers, buds, leaves) that are often consumed tend not to be preserved, and so there may be little indication of such plant exploitation in the archaeobotanical record. In addition, historic descriptions commonly noted an abundance of resources like hazelnuts, plums, grapes and strawberries bordering the treeless openings (Sears 1926b). Early observers also commented on how attractive these habitats were to deer, elk and turkey. Thus, while not "huge prehistoric grocery stores," as swamps of the Lower Mississippi Valley have been described (F. Hamilton, p.c.), the wet prairie and swamp habitats were probably rich in wild resources.

This brief evaluation of some possible factors that might be relevant to explaining geographic patterning in isotopic diet among Late Prehistoric populations of the study region has eliminated the hypothesis that the availability of suitable soils was a limiting factor. The greater frequency of historically-documented summer drought conditions in southwest Ohio and the common occurrence of resource-rich swamp and "prairie" habitats on the Till Plains both remain potential factors by which to account for the observed pattern in $\delta^{13}C$ values.

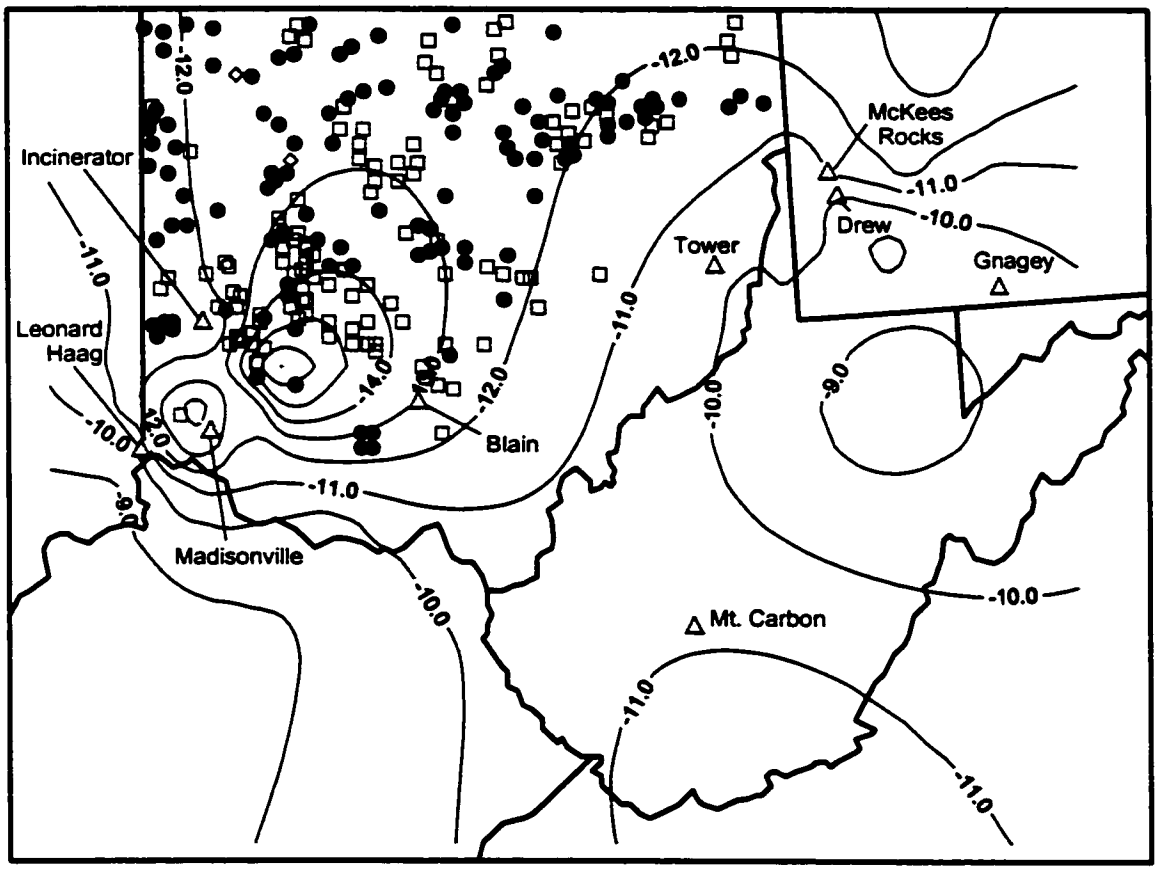


Figure 77. **Relationship between $\delta^{13}C$ values during the middle Late Prehistoric period (isolines) and treeless areas of the study region.** Treeless areas (Sears 1926b) are bogs/swamps/wet prairies (●), dry prairies (◇) and wet or dry prairies/barrens (□). Archaeological locales with prairie/grassland faunal taxa (△) are indicated also.

ASSESSING PREHISTORIC ECOLOGICAL DISTURBANCE

The modern forest associations of the Eastern Woodlands just described are known to be of recent origin, on the order of 2-3000 years (Davis 1969). Since the establishment of these forest associations and until Euroamerican disturbance, the vegetation is believed to have undergone only relatively modest changes (Clark et al. 1996). Establishing what roles factors such as climate change and human activities may have played in these subtle changes has not been a simple task. Amerindian agricultural and hunting activities almost certainly impacted the vegetation and animal regime, but determining precisely the degree of disturbance has been a difficult and contentious task.

The literature describes two polar views of the role of Amerindians in shaping the landscape of eastern North America. Some (e.g., Day 1953; Martin 1973; Maxwell 1910; Pyne 1982) have suggested that a significant part of the landscape was in open woodlands, large grasslands and old agricultural fields created and maintained by Native American burning activities. Others (e.g., Campbell and Campbell 1994; Forman and Russell 1983; Raup 1937; Russell 1983) have argued that the open forests were natural occurrences and that forest disturbance by Indians was largely restricted to small areas around settlements that were cleared for agricultural purposes, in the search for firewood, and by occasional accidentally-escaped campfires. The huge disparity between the two views is probably due in large part to the kinds of data available.

The most frequently cited sources of information about aboriginal landscape disturbance are historical descriptions of the landscape and of Amerindian practices by early Euroamerican settlers and explorers. Taken as a set, however, these historic documents are difficult to interpret. First, the reports were often designed to appeal to different audiences, e.g., potential settlers or investors, thus exaggerating particular characteristics of the landscape, and most make only brief mention of the vegetation or Native American practices (Russell 1983).

Second, the vegetation is often described in ambiguous terms (e.g., parklands, prairies, meadows, barrens and clearings) that mean different things to different people. Third, there must certainly be sampling bias – the documents describe only settled and explored locales, the earliest of which were probably restricted to easily accessed areas along coastlines, river valleys, and established trails. By the time other areas were explored, evidence of disturbance may have been obliterated by processes of forest succession. And, finally, the use of historic documents requires that we make the questionable assumption that the activities of Amerindian populations, as described in the 16th, 17th and 18th centuries, were relatively unaffected by the consequences (introduced disease, increased warfare, economic reorganization) of Contact; i.e., if there is no historic documentation of proscribed burning by native groups in some locale, then they are assumed to have not been involved in such activities at an earlier time.

Most of this debate centers on the forests of New England and along the Atlantic coast, the locus of many of the historic documents. However, there is no reason to expect that conclusions drawn for those areas (e.g., Bromley 1935; Hammett 1992; Niering and Goodwin 1962; Ogden 1961; Patterson and Sassaman 1988; Siccama 1971) can be extended to the middle and upper Ohio River valleys. Both the prehistoric subsistence systems of these regions and the trajectories of their populations differed significantly. More importantly, the Ohio Valley was entered by Euroamerican explorers long after the area had been depopulated. Although historic descriptions of portions of the Ohio Valley do document the existence of vegetative features such as old (abandoned) fields, prairies, meadows, and barrens which are often attributed to Amerindian activities (Ketchum 1864; Maxwell 1910; Michaux 1904a, 1904b), it is not clear what fraction of the landscape was so altered. Additionally, one wonders how much of the landscape had already recovered by the time anybody was there to describe it (cf. Campbell 1987; Maxwell 1910).

One approach might be to examine lake and bog sediments, which are known to preserve palynological and sedimentological evidence of ecological change in their vicinities. The challenge is to distinguish ecological changes due to human activities from those due to climatic factors. Research into the effects of historic Euroamerican landscape alterations on nearby watersheds (e.g., Brugam 1978; Brugam and Speziale 1983; Davis 1976; Engstrom et al. 1985) has identified the kinds of changes that might accompany human ecological disturbances. Although the magnitude of Amerindian ecological disturbance will be more subtle than the historic situation, there is no reason why such an approach might not be useful in the Eastern Woodlands. Indeed, there have been some exciting applications of this approach. Consider, for example, the pollen record from Tuskegee Pond in eastern Tennessee (Delcourt 1987; Delcourt and Delcourt 1985; Delcourt et al. 1986). There, significant increases in the relative abundance of herbaceous pollen types (including *Zea mays*, *Chenopodium*, *Iva* and *Ambrosia*), charcoal fragments, and lacustrine sediments over the past 1500 years were documented. Comparable changes were not found in a nearby core, indicating that Tuskegee Pond was reflecting localized land clearance events and not regional climatic change.

Evidence for prehistoric ecological disturbance was also recognized in cores from Second, Gignac and Crawford lakes in southern Ontario (Burden et al. 1986a, 1986b; McAndrews and Boyko-Diakonow 1989). Palynological and sedimentological data consistent with prehistoric forest clearance and maize farming were identified in sediments dated ca. A.D. 1400. In particular, pollen from primary forest taxa (maple [*Acer*] and beech [*Fagus*]) decreased as pollen from pioneer trees (oak [*Quercus*] and pine [*Pinus*]) and herbs (bracken fern [*Pteridium*], purslane [*Portulaca*] and grasses [Gramineae]) increased; maize pollen was identified, as well. Corresponding changes in sediment geochemistry and mineralogy at Second and Gignac Lakes were consistent with erosion associated with deforestation and agriculture. Increased concentrations of wood charcoal fragments in Crawford Lake sediments were shown to be coeval with the declining

primary forest and increasing herbaceous taxa (Clark 1995; Clark and Royall 1995), thus providing further support for the identification of prehistoric human disturbance of the forest. The distinction between human and climatic factors is not always as clear cut as it may seem, however. Even in the case of Crawford Lake, where several kinds of evidence seemingly support the notion of prehistoric land clearance, an argument has been advanced that the changes in forest taxa may instead reflect vegetative responses to Little Ice Age cooling (Campbell and Campbell 1993; Campbell and McAndrews 1991, 1993, 1995).

The prairies in central Kentucky known as the "Barrenlands" or simply the "Barrens" present a similar dilemma. Early explorers in Kentucky (e.g., Filson 1797; Michaux 1904a) noted these ecosystems, dominated by grasses with occasional oaks, and remarked that they replaced the natural forests which had been eliminated through regular burning events by the native inhabitants. Others (e.g., Transeau 1935) believed that the Barrens were remnants from the southeastward expansion of the Prairie Peninsula during the Hypsithermal (7500 – 3500 B.P.). Analysis of a pollen sequence from Jackson Pond in eastern Kentucky, though, indicated that the Barrens were established sometime after the Hypsithermal (Wilkins et al. 1991). Indeed, both Gramineae and *Quercus* pollen increased significantly after 2000 BP. While this may increase the likelihood of human involvement in the creation of the Barrens, it does not eliminate the possible role of climatic change (Baskin and Baskin 1987; Wilkins et al. 1991). The notion that people were actively manipulating the landscape in the region appears to be supported by the fossil pollen and charcoal records from Cliff Palace Pond in eastern Kentucky, where a substantial increase at 3000 B.P. in charcoal and in pollen of fire-tolerant, ruderal and cultivated taxa was documented (Delcourt et al. 1998).

In other parts of the world, archaeologists have documented impacts of prehistoric human exploitation of native faunas (Grayson 2001). To date, there have been no clearly documented cases of depressed faunal populations resulting

from human predation in the study region. Indeed, assemblages of the Tombigbee River valley (Welch 1990) provide the only evidence of faunal shortages due to overhunting in eastern North America of which I am aware; even when such has been explicitly sought (e.g., Smith 1975), it has not been found. Although this may be because appropriate methods have not been applied, it is perhaps more likely to be a consequence of swidden farming, which creates the kinds of habitats preferred by several economically-important faunal taxa.

From this review, direct evidence for prehistoric alteration of the ecology of the Eastern Woodlands is limited. Historic documents suggest that Amerindian populations may have been a significant factor in creating the landscape that the Europeans encountered. Although few pollen cores provide clear evidence in support of human alterations of the ecological landscape, few paleoecologists have actually examined the relevant time period in enough detail to identify such alterations if they indeed occurred. Similarly, the archaeofaunal record has not received the kind of attention required to detect human impact on animal populations in the region. The role of Late Holocene climate change in altering the forests of the Eastern Woodlands has received relatively greater attention. Climate during the past 2000 years is important to this study because of its potential impact on human subsistence systems.

CLIMATE

The modern climate in the study area is essentially humid and continental, characterized by cold winters and warm summers, with moderate to high extremes in both temperature and precipitation. Spatially, weather patterns are complex, with considerable variation from one locale to another, depending upon features such as topography and latitude (Ruffner 1985). To better understand the influence this variation might have had on subsistence, the regional climate is considered briefly, emphasizing those properties that plant ecologists (Braun 1964;

Collinson 1988; Crawley 1986b; Daubenmire 1974; Walter 1979) identify as most critical to the distribution and productivity of vegetation: minimum winter temperatures, dates of last spring and first fall frosts ($\leq$ 0°C), length of frost-free season, minimum and maximum summer temperatures, and the severity of summer drought conditions.

Year-to-year variation, or predictability, in climatic parameters like those above is known to be more influential than the average on plant yields (Riha et al. 1996) and, hence, will be important to explaining the success of subsistence systems. Climatic variation is particularly critical to specialized systems, which rely on a few related taxa; generalized subsistence systems, which utilize many unrelated taxa, are more resilient. For the latter, bad years for one resource are not necessarily fatal – decreased productivity of one resource may be compensated for by increased yields of other unrelated resources. This has been nicely illustrated by Grove (1988) in her review of climatic, economic, and demographic data for historic human populations in several geographic areas, including Iceland, Greenland, Norway, and Scotland. Consistent with such observations, this assessment of the potential influence of climatic factors on subsistence will include the spatial patterning of standard deviations for the relevant climatic parameters rather than their mean values alone.

The data for this discussion are obtained primarily from the U.S. Historical Climatology Network (Karl et al. 1990). The USHCN data set consists of historical records of monthly mean, maximum, and minimum temperature and total precipitation for 1221 meteorological stations across the continental United States. These data have been screened for suspect values and corrected for several biases, specifically time-of-observation, thermometer changes, station movements, and urban warming (Jones et al. 1990; Karl et al. 1995a, 1986, 1988; Karl and Williams 1987; Quayle et al. 1991). In addition to the 66 meteorological stations that are located in or very near the study area (Figure 78), 82 stations outside the borders of

the mapped area were used to extend contour lines, thereby eliminating edge effects. The records of these 148 stations (listed in Appendix E) range in length from 65 to 162 years; the minimum period of time covered by these records extends from 1931 – 1996, with some extending as far back as the year 1834.



Figure 78. **The 3-dimensional location of 66 meteorological stations in and around the study area.** Contour lines and fill reflect station elevation in feet above mean sea level; low elevations are in dark fill and high elevations are in light fill. The interval is 200 feet. This is not an accurate reflection of regional topography.

Uncorrected data regarding the length and timing of the frost-free season have been compiled for the same meteorological stations from state climatological records published by the U. S. Weather Bureau, the U.S. Environmental Science Service of the U.S. Department of Commerce, the U.S. Environmental Data Service, and the Environmental Data and Information Service

of NOAA (National Oceanic and Atmospheric Administration) for the years 1948 – 1995. While uncorrected station biases (e.g., changes in the kind or situation of instrumentation, the time of observation, or the degree of urbanization of the surrounding area), known as inhomogeneities, can produce patterns through time that might be mistaken for climate change (Cooter and LeDuc 1995), it is unlikely that the influence of such errors on the distribution of long term means and standard deviations for such a large number of stations will be systematic.

MODERN CLIMATIC VARIATION IN THE STUDY AREA

Modern mean minimum winter (December – February) temperature is plotted in Figure 79. Mean values are depicted by contour lines, which increase in thickness as values become more extreme. Standard deviations, divided into four equal intervals via the n-tile technique (Jermann and Dunnell 1979), are shown by the fill; very light gray represents the first and lowest class of values, shading into darker grays as the standard deviation increases. White symbols indicate the location of relevant archaeological deposits. All of the other plots which follow use the same mapping conventions.

The overall pattern of modern winter minimum temperatures corresponds well to the regional geography, with extreme lows at higher elevations and higher latitudes. The eastern portion of the study area has both high mean winter minimum temperatures and low temperature variation, probably due to its proximity to the moderating influence of the Atlantic Ocean. The northwestern portion shows lower winter minimum temperatures coupled with greater variation, reflecting the effects of Arctic cold fronts.

That the geographical distributions of plant species are often limited by low winter temperatures is well established by plant ecologists. This is because plants have no active mechanisms (e.g., antifreeze) to protect themselves against tissue damage resulting from the formation of intra- and extra-cellular ice.



Figure 79. **Modern mean minimum winter (DJF) temperature (°C) across the study area.** The contour interval is 0.5 °C; SDs range from ± 1.45 to 2.34 °C. Light fill indicates small SDs and dark fill indicates large SDs. Symbols represent archaeological locales.

Deciduous broad-leaved species, which comprise most of the native vegetation of the region, have winter low temperature thresholds ranging between -15 and -40 °C, or lower (Woodward 1987). Figure 79 suggests that the death of native perennial plants due to low winter temperatures will be a rare occurrence. Indeed, for the total 14,622 winter records at the 148 weather stations considered here, minimum winter temperatures dipped below -15 °C only twice. Neither the spatial distribution of archaeological locales nor the nature of subsistence systems appear to be patterned within the study region with respect to modern winter minimum temperature.

Resistance to low winter temperatures requires physiological changes in the plant; these changes, known as "hardening," are typically accomplished when growth stops in the autumn and they are reversed (called "dehardening") as growth begins again in the spring. In the absence of such conditioning, plants are susceptible to freezing damage. Thus, sudden and unusually early autumn and late spring frosts can do significant damage (Cooter and LeDuc 1995; Daubenmire 1974; Walter 1979). Figures 80 and 81 plot the modern occurrence of last spring and first autumn frosts (≤ 0 °C) as the number of days since 1 January. In Figure 80, the mean date and standard deviation of the last spring frost correspond well to the latitudinal and topographic situations of the meteorological stations. That cold air



Figure 80. **Modern mean last spring freeze (days since 1 January).** The contour interval is 5 days; SDs range from ± 8.30 to 26.42 days. Light fill indicates small SDs and dark fill indicates large SDs. Symbols represent archaeological locales.

drainage into valley floors of mountainous areas typically leads to later and more variable spring frosts is supported. This pattern is less apparent for first autumn frosts in Figure 81, where mountainous areas display a slightly earlier mean date, but not necessarily greater variation.

The consequences of late spring and early autumn frosts, while potentially damaging to the fruit and nut yields of native plants (Kozlowski 1983), can be particularly devastating for non-native cultigens (Daubenmire 1974). Plants of tropical origin, like maize, are especially susceptible to loss due to frost damage



Figure 81. **Modern mean first autumn freeze (days since 1 January).** The contour interval is 5 days; SDs range from ± 8.38 to 15.82 days. Light fill indicates small SDs and dark fill indicates large SDs. Symbols represent archaeological locales.

in temperate regions. Spring frosts that occur before the plants have emerged above the soil surface are not problematic, but a late spring frost following the plants' emergence from the soil may destroy an entire crop (Shaw and Newman 1991), requiring that it be replanted. Later plantings not only generally reduce crop yields (Nelson et al. 1992; Nolte and Duvick 1986), but in pushing back the harvest date, they also increase the risk of crop damage by early autumn frosts. From Figure 80, it is quite clear from the modern data that locales in the Upper Valley would have experienced a later- and more variably-starting frost-free season than locales elsewhere in the study region.

Early autumn frosts may damage fruit before it has fully ripened, affecting its edibility and/or storability. One wonders if the basis for "green corn" ceremonialism (Swanton 1946; Witthoft 1949) rests with using maize crops damaged by early autumn frosts. Using modern data, Figure 81 shows that some of the Upper Valley settlements would have experienced a rather early mean autumn frost, but most are not very different from elsewhere. Pockets of high variation in the timing of first fall frosts (but still less variable than for the last spring freeze) occur throughout in the region. At any rate, growing crops in those locales where the timing of late spring and early autumn frosts is highly variable is a tricky venture. This is particularly true when high variability in the timing of frost events is associated with a short mean frost-free season which approaches that required for the maturity of a particular species.

The length of the frost-free season is critical to the success of many introduced agricultural crops, much less so for most native plants (Daubenmire 1974). As a consequence, frost-free season length was likely a limiting variable for the distribution of Late Prehistoric subsistence systems which emphasized non-native plants, much as it is today. Indeed, Yarnell (1964) found that archaeological deposits with remains of maize and other cultigens (beans, gourd/squash and sunflower) are restricted to areas currently with greater than 120 frost-free days.

Noting that modern maize requires only 60 – 70 days to mature, he suggested that the extra time was necessary to avoid damage by unanticipated late spring and early autumn frosts.

Figure 82 shows the modern distribution of frost-free season length over the study area. As anticipated, the frost-free season decreases in mountainous areas and to the north. Populations living in the Upper Valley and in the mountainous eastern part of the study region experienced a shorter frost-free season than elsewhere. Any problems associated with a shorter frost-free season in those areas were probably compounded by greater variation in its length than

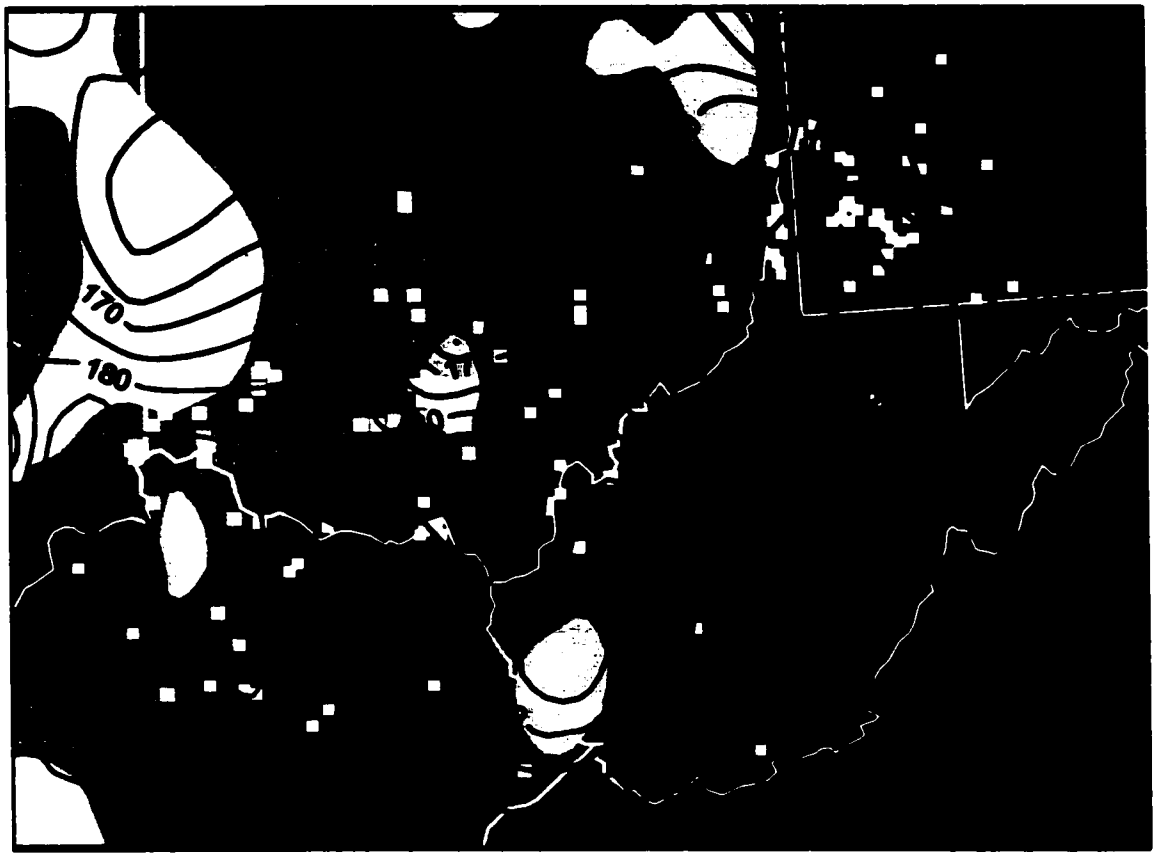


Figure 82. **Modern mean frost-free season length (days between last and first frosts).** The contour interval is 5 days; SDs range from ± 11.37 to 27.09 days. Light fill indicates small SDs and dark fill indicates large SDs. Symbols represent archaeological locales.

experienced by most parts of the study region. Since cooler climatic episodes tend to be associated with shorter frost-free seasons (Lindsey and Schmelz 1965), the impact of climatic cooling on the Upper Valley would be greater than elsewhere in the region.

Air temperature conditions during the growing season are also relevant to this discussion because the rates of biochemical reactions in plants are temperature-dependent (Crawley 1986a; West 1953). As a result of low temperatures during the growing season, plants may experience reduced photosynthesis and growth, leading to late flowering and low fruit/grain production. Again, introduced tropical plants like maize would be particularly susceptible to low summer temperatures (Dale 1983; McWilliam 1983). Figure 83 shows the modern distribution of mean summer minimum temperatures across the study area. There are clear geographic and topographic patterns in the distribution of the mean. The distribution of standard deviations shows relatively little variation across the region, with the exception of a few small pockets. As pointed out in the discussion on frost-free season, populations living in the mountains to the East probably were impacted more by episodes of cool climate than elsewhere in the study region.

High summer temperatures can also wreak havoc on plant life. High temperatures may upset the balance between photosynthesis and respiration, the end result being decreased growth and reproduction (Dale 1983; Kozlowski 1983; Shaw 1983). Cell metabolism is disturbed when plant temperatures exceed 40 °C (Crawley 1986a). To be lethal, however, temperatures in the range of 50 – 60 °C are often required (Daubenmire 1974). Modern mean summer maximum temperatures in the study area are shown in Figure 84; not unexpectedly, the areas with the highest mean summer temperatures tend to experience the greatest variation in temperature. The mean temperature maxima are well below the lethal range. Out of 14,560 summers documented in the data set, none had a summer maximum

temperature above 40 °C. This variable, then, is not likely relevant to understanding variation in prehistoric subsistence.

One final parameter considered here is the severity of drought conditions during the growing season. Droughts can significantly inhibit plant growth and decrease fruit, nut or seed yields (Kozlowski 1983; Shaw 1983). An index developed by Walter (1979) provides one way to estimate potential drought conditions in the absence of data about soil moisture capacity. The index relies on the notion that the availability of soil moisture is a function of precipitation minus evapotranspiration, the latter known to correlate with mean monthly temperature.

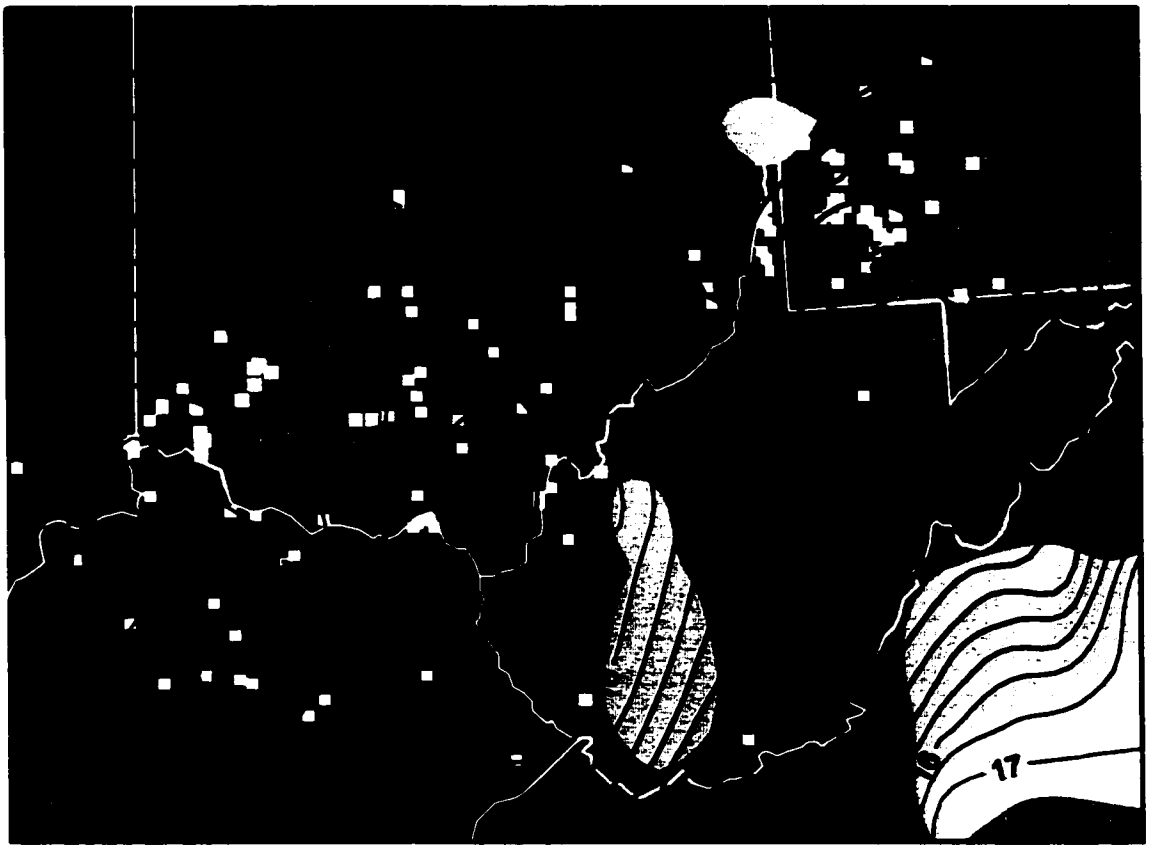


Figure 83. **Modern mean summer minimum temperature (°C).** The contour interval is 0.5 °C; SDs range from ± 0.63 to 1.46 °C. Light fill indicates small SDs and dark fill indicates large SDs. Symbols represent archaeological locales.

Calculating the index (I) requires mean monthly temperature (T) and total monthly precipitation (P) be scaled such that 10 °C = 20 mm rain (Neilson 1986; Walter 1979). When the index (I = P – 2T) is positive, precipitation has exceeded evapotranspiration and drought conditions do not obtain; when I is negative, drought conditions are in force.



Figure 84. **Modern mean summer maximum temperature (°C).** The contour interval is 0.5 °C; SDs range from ± 0.84 to 1.74 °C. Light fill indicates small SDs and dark fill indicates large SDs. Symbols represent archaeological locales.

Figure 85 plots the mean drought index calculated for the three summer months June, July and August. The index is highly positive, indicating that summer droughts are either not particularly severe, are of short duration (and thus are mathematically insignificant on a seasonal basis), or occur relatively rarely. In looking at the summer monthly data on a year-by-year basis, negative



Figure 85. **Modern mean summer drought index.** Contour interval is 5; SDs range from 21.85 to 63.34. Light fill indicates small SDs and dark fill indicates large SDs. Symbols represent archaeological locales.

values indicating drought conditions are not uncommon; approximately 12% (± 5% [1 SD]) of all summer months measured indicated drought conditions. It is unusual for such conditions to carry over into two months, however, and so the index reflecting the summer mean for any given year is rarely negative. Consequently, a relatively short drought duration is one factor. Drought severity, as indicated by the negativity of the index, is often relatively mild, although severe droughts (with values to -58.0) are not unknown. The large standard deviations of Figure 85 indicate highly variable summer temperature/precipitation conditions. Together, these data are consistent with the notion that severe summer droughts are a relatively rare and short-lived occurrence.

Although the average modern drought index is positive overall, it appears to be smallest in western Ohio and eastern Indiana and it is greatest in the mountainous areas to the eastern part of the study region. This indicates that drought conditions are more frequent and/or more severe in the western portion of the study region. When the relative frequency of modern summer months with drought conditions (i.e., a negative drought index) is examined for geographic patterning (Figure 86), the greatest frequencies in the study region are indeed found

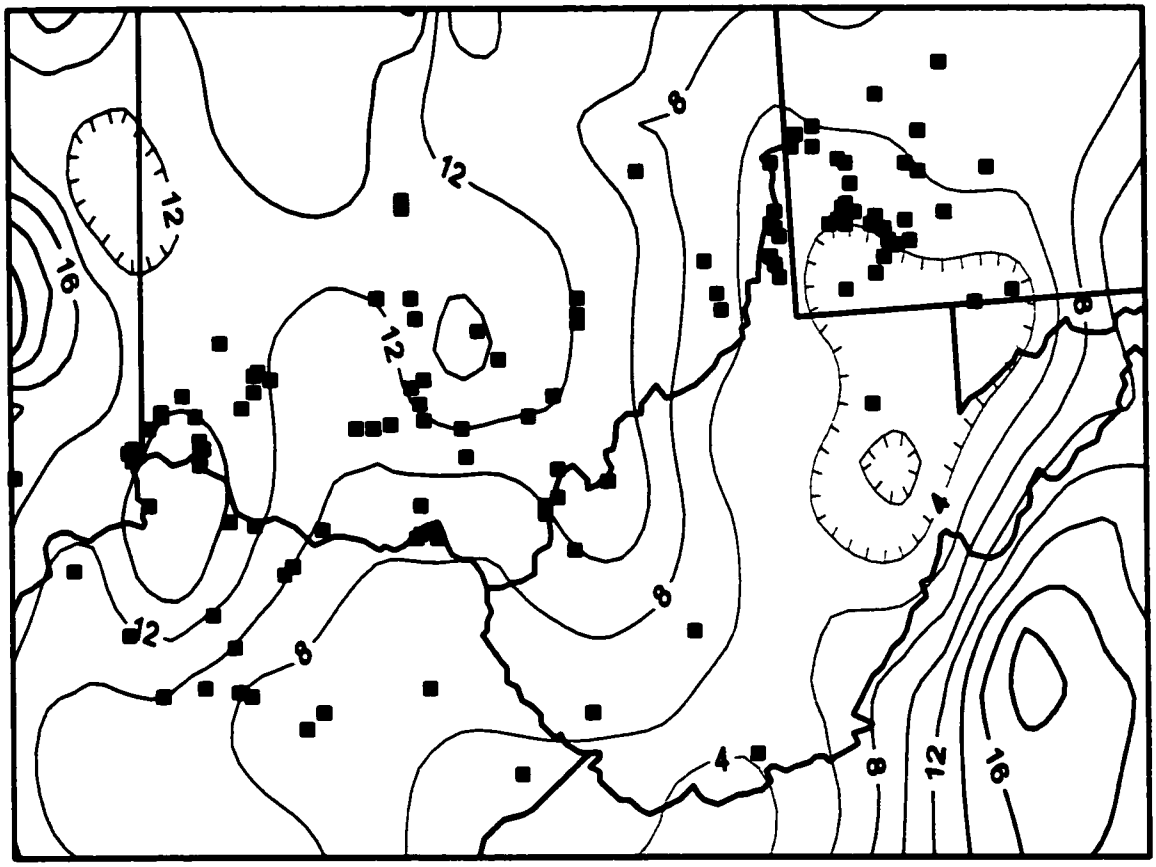


Figure 86. **Relative frequency (%) of modern summer months (June, July, August) with a negative drought index.** Black symbols represent archaeological locales.

in eastern Indiana and southwest/central Ohio. In that area, roughly one of every eight summer months experienced drought conditions (evapotranspiration exceeded precipitation).

Recall that Late Prehistoric $\delta^{13}C$ values in southwest and central Ohio tend to be depleted relative to other areas of the study region. Figure 87 compares those $\delta^{13}C$ values against the modern drought frequency data. The correlation is not particularly convincing, but the underlying spatial distributions of data upon which these maps are based, particularly the isotopic one, are not ideal. A larger sample of spatially-dispersed stable carbon isotope analyses is necessary to better evaluate drought frequency as a potential factor in explaining variation in isotopic diet. At

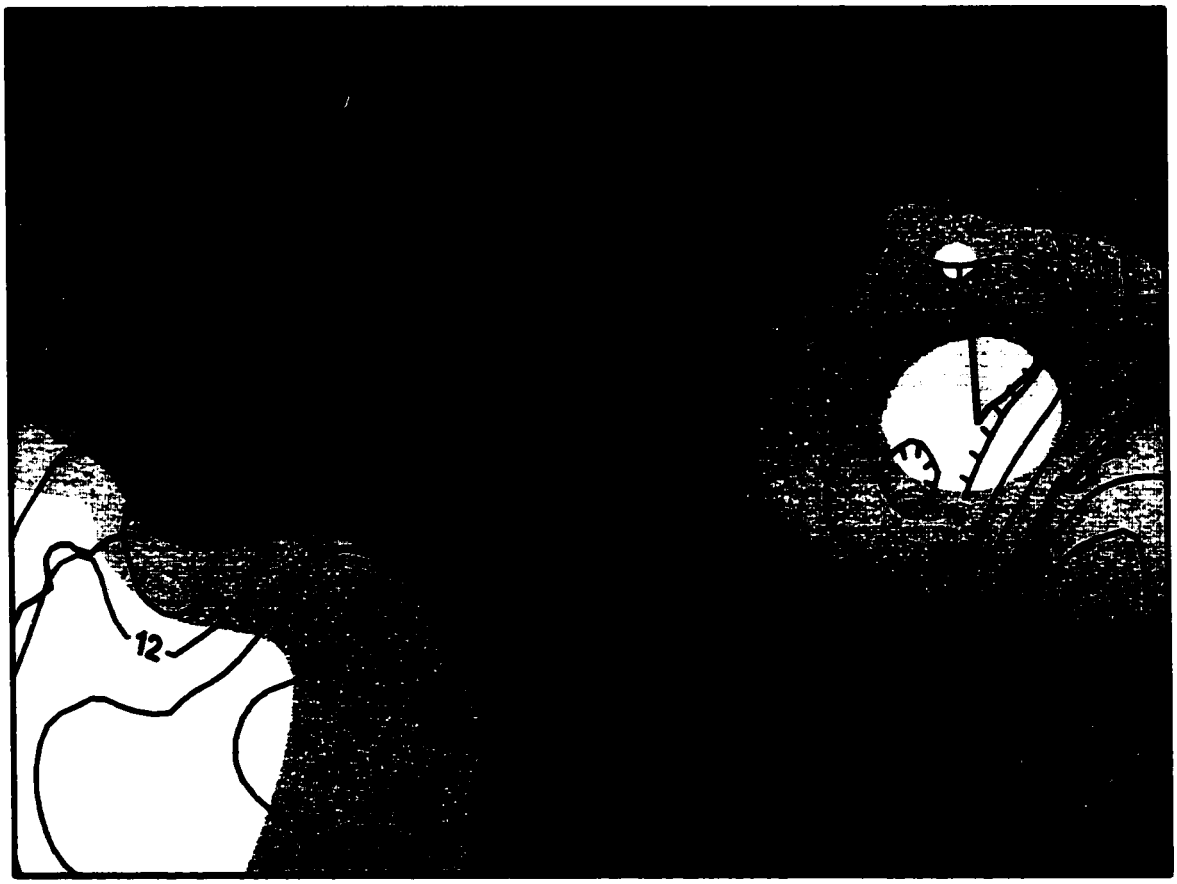


Figure 87. **Relative frequency of modern negative drought index (isolines) and mean $\delta^{13}C$ values during the middle Late Prehistoric period (background).** Relatively depleted $\delta^{13}C$ values are indicated by darker fill and enriched $\delta^{13}C$ values are indicated by lighter fill. Compare with Figure 65 for actual $\delta^{13}C$ values.

any rate, if patterns in modern climate are applicable to the prehistoric past, warmer and/or drier climatic episodes should impact subsistence systems of western and central Ohio to a greater extent than elsewhere in the study region.

Relevance of Modern Climate

There is considerable evidence that climatic conditions have not been constant over the past 2000 years. Indeed, historic temperature and precipitation records document climatic variation on multiple temporal and geographic scales (Houghton et al. 1996; Karl et al. 1995b; Mann et al. 1995, 1998; Palecki 1994; Schlesinger and Ramankutty 1994). It is also true that we do not know the growing requirements of prehistoric plants. One might suppose, then, that modern climatic data are not relevant to explaining prehistoric subsistence change.

Understanding the geographic patterns of modern climatic variability, however, may provide insight into prehistoric conditions. For instance, areas that today are characterized by a highly variable frost-free season relative to other locales probably experienced similar variation prehistorically, even if the actual length of the frost-free season differed. We can use that approach, as did Yarnell (1964), to look for correspondence between the spatial distributions of modern climatic parameters, prehistoric agricultural locales and subsistence variation. Yarnell's work is expanded here by emphasizing variation in, as well as means of, frost-free season length (cf. Campbell and Campbell 1992). Spatial distributions of other modern climatic parameters are also examined for additional insights into the relationship between prehistoric subsistence and environment. Finally, paleoclimatic data are used to gauge the potential impact of climate change on subsistence variation in the study region.

MODELS OF CLIMATIC CHANGE

Documenting the timing, direction and probable magnitude of past climatic changes is possible because climate influences the nature and rate of many geological and biological processes, thereby leaving records of varying precision for past climate in many kinds of materials. Records of Late Holocene climatic change derived from elsewhere are not necessarily applicable to eastern North America. Evidence is mounting that well-documented events such as the Medieval Warm Period (ca. A.D. 1000 – 1200) and the Little Ice Age (ca. A.D. 1430 – 1850) were not of the same magnitude, timing or duration globally or even across North America (Bradley and Jones 1993; Deming 1995; Gribben and Lamb 1978; Hughes and Diaz 1994; Jones and Bradley 1992; Keigwin 1996; Kreutz et al. 1997; Nicholls et al. 1996; Pielou 1991; Williams and Wigley 1983). Although the concept of teleconnection (which posits that geographically-separate weather systems are linked by air circulation patterns) suggests climate change in at least some areas may be correlated, it does not guarantee predictability from one region to another. Climatic change is complex and the models often referred to by archaeologists working in eastern North America may not be appropriate because they rely heavily on northern European and American Southwest climatic records.

HISTORICAL REVIEW OF CLIMATIC MODELS DERIVED FOR EASTERN NORTH AMERICA

One of the earliest empirically-derived models of post-glacial climatic change in eastern North America was developed by Sears (1932). Based on analyses of fossil pollen from several deposits located throughout the Eastern Woodlands (including Ohio and Indiana), Sears established a sequence of climatic changes that paralleled those documented for northern Europe. Since the radiocarbon dating method had not yet been developed, his chronology was based on estimates of the rate of peat formation and on comparisons with the European sequence. Although his analyses emphasized climates of the early and middle Holocene, Sears' reconstructions did include some generalizations about the past 2000 years.

Specifically, he claimed eastern North America witnessed a gradual increase in humidity, while remaining relatively warm, over the past 2000 years. Of particular note is his interest in correlations between climatic conditions and prehistoric cultural phenomena, especially the distribution of maize farmers.

Griffin's (1960, 1961) model of climate change in eastern North America relied on climatic reconstructions from the southwestern United States, northern Europe and elsewhere. In his initial formulation, Griffin (1960) was primarily concerned with changes in temperature; later, he (Griffin 1961) included precipitation in his model, as well. He posited four climatic episodes during the relevant time period (Figure 88) and, as did Sears, emphasized their correspondence with prehistoric cultural changes. Vickery (1970), citing pollen data from the Midwest, noted that the climate became cooler and moister in A.D. 300, thus providing support for that part of Griffin's model.

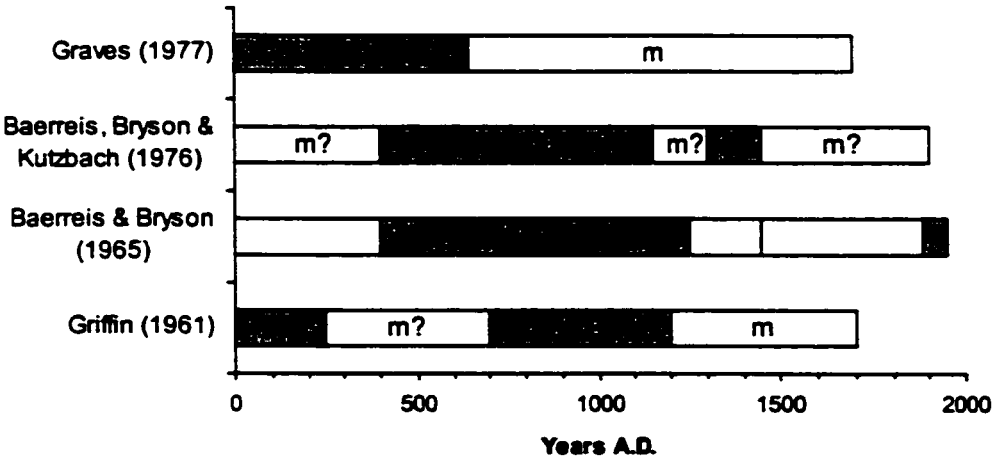


Figure 88. **Models derived to describe climatic conditions in eastern North America over the past 2000 years.** White = cool; gray = warm; d = drier; d? = possibly drier; m = moister; m? = possibly moister.

Baerreis and Bryson (1965), like Griffin, relied primarily on records from other parts of the world in their scheme. They proposed a less definite outline of climatic change in the Eastern Woodlands (Figure 88). By "less definite," I

simply mean that, acknowledging difficulties using data from distant locales to reconstruct particular climatic conditions in eastern North America, they often used general terms like "milder" or "more severe" rather than specific terms like "warmer and wetter" or "colder and drier." Their scheme differs from that of Griffin in the character of the earliest two climatic episodes considered here. Whereas Griffin (1960, 1961) originally proposed that the end of the Hopewell and the beginning of the Late Woodland phenomena were correlated with the onset of cooler conditions (ca. A.D. 200 – 300), Baerreis and Bryson (1965) suggested that the climate became milder (i.e., warmer and perhaps drier) slightly later (ca. A.D. 400). It is possible that these differences reflect problems associated with establishing the timing of climatic episodes rather than wholesale misinterpretation of the climatic data.

Based largely on the analysis of pollen in varved sediments from Hell's Kitchen Lake in northern Wisconsin, but also incorporating climatic data from elsewhere (particularly the southwestern U.S. and the Plains) and models of atmospheric circulation, Baerreis et al. (1976) refined their earlier model. Although its overall structure is similar to the earlier version, the revised model (Figure 88) is more detailed and it contains a brief warmer or drier episode dating to A.D. 1250 – 1400 that was not described previously.

Finally, there is the model of Graves (1977, cited in Church 1987). This model is based on pollen data from Silver Lake in west central Ohio (Ogden 1966), with comparisons to Pretty Lake in northeastern Indiana and Soden Lake in southern Michigan. The sequence of climatic change, based on local pollen records just north of the study area, is quite different from that of the other models (Figure 88). Of particular interest is the observation that the end of the Hopewell phenomena and the beginning of the Late Woodland period may not correlate with any significant climatic shifts.

The inconsistencies among the different scenarios suggest that past climatic conditions may have been geographically variable and that any of the

current climatic models should not be simply assumed to be applicable to the study area. Further evaluation of relevant climatic data is warranted. As part of this research, a new climatic model (Appendix I) was developed.

A New Model of Climatic Change in the Ohio Valley

The new climatic model was developed from an analysis of relevant published paleoclimatic records from four different sources (palynological data, beach ridge deposits, tree rings and boreholes) and high-resolution macrophysical models of paleoclimate. Although paleoclimatic data from the study area would provide the best local source of climatic information, there are few data from the region and so the records of immediately surrounding areas were particularly important. As detailed in Appendix I, for each kind of record, temperature and/or moisture signals were identified and their variation over the past 2000 years was tracked. When the records from different areas (e.g., west and east of the study area) were compared, similarities in the timing and direction of the different data sources were treated as concurrent climatic events that were likely to be regional in scale, and thus probably affected the study area as well. These sequences for the different data sources are combined to produce the new climatic model.

Figure 89 shows the final sequence of climatic regimes derived from proxy climate data in Appendix I and presented in a format comparable to the models described earlier. Although it has some features in common with the other attempts, it is, on the whole, rather different from them. It is important to point out that this climatic sequence was developed independently and without reference to the Ohio Valley archaeological record. This new model provides a new perspective on the impact of climate change on prehistoric populations; it is no longer acceptable to assume that no significant change in climate occurred in the Eastern Woodlands over the past 2000 years.

Although having information about the magnitude of climatic change would be useful in establishing its specific impacts on subsistence, those data are not available. Evidence regarding the timing and direction of change is thus critical. What I seek here are correlations in the timing of climatic episodes and the archaeological record. When such correlations occur, the nature of the correlation is examined to establish if and how a varying climate altered the selective conditions for subsistence, thereby accounting for subsistence change.

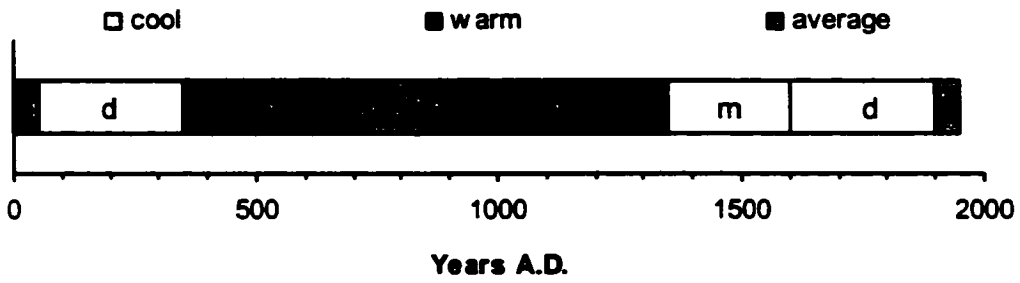


Figure 89. **Model of climatic change for the study region for the past 2000 years.** Fill color indicates relative summer temperature. Letters indicate relative annual precipitation with d = dry and m = moist; no letter indicates average precipitation.

CLIMATIC CHANGE AND THE OHIO VALLEY ARCHAEOLOGICAL RECORD

Figure 90 shows the distribution of locales (with subsistence data) in my sample that could be identified as to type (sedentary settlement, seasonal logistic camp, and mortuary facility) with respect to the climatic model. It is quite obvious that deposits in the age range A.D. 700 – 900, corresponding to a time of relatively cooler and drier climate sandwiched between warmer and wetter climatic episodes, are underrepresented. This pattern apparently reflects settlement dispersion during that time span; those settlements are less visible archaeologically and have received less systematic study. The consequence is that subsistence data that might prove a keen test of the impact of climate on subsistence variation are

not available. As it currently stands, what knowledge we do have regarding subsistence during the time span A.D. 700 – 900 may simply be an artifact of sampling.

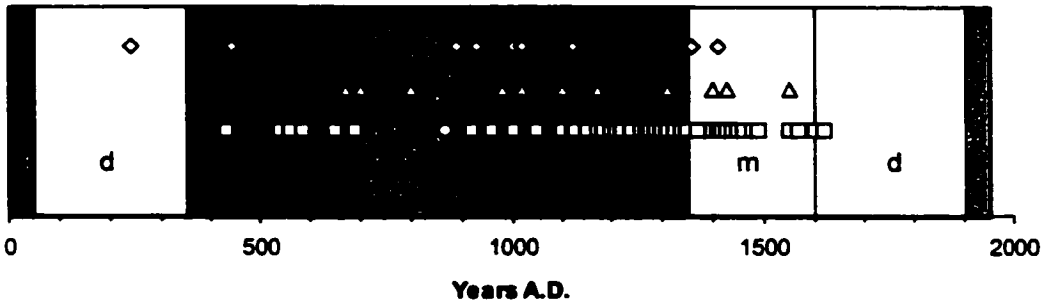


Figure 90. **Distribution of different site types with respect to the new climatic model.** □, nucleated sedentary village (n = 89); O, dispersed sedentary hamlet (n = 1); Δ, seasonal logistic camp (n = 14); ◇, mortuary facility (n = 10). Fill color indicates relative summer temperature (white = cool; gray = average; black = warm); letters indicate relative annual precipitation with d = dry and m = moist. Site type data in Appendix B.

It is worthwhile to consider briefly the settlement record. Dunnell and Greenlee (1999) previously noted an apparent correlation between the appearance of nucleated sedentary settlements at the beginning of the Late Woodland period (ca. A.D. 400) and a change toward warmer and wetter conditions (ca. A.D. 350). Even in the face of a more detailed examination of proxy climate data, this correlation between settlement reorganization and climatic change appears to stand. The southeastern tree ring sequence also suggests a highly variable climate during this generally warmer and wetter episode (Appendix I). If true for the study region as well, a variable climate could account for the apparent instability (i.e., low permanence) of these first nucleated settlements.[36] Finally, the

[36] Low permanence is evidenced by relatively thin middens, insubstantial structures, and artifact types restricted to a short period of time (cf. Rafferty 1985).

argument implicating climatic change as a factor in settlement nucleation during the Late Woodland period is perhaps made stronger by the observation that settlement dispersion (ca. A.D. 750) follows a return to relatively cooler and drier conditions ca. A.D. 700.

As noted earlier, nucleated sedentary settlements apparently reappear shortly after the second warmer and wetter climatic episode began in ca. A.D. 900, and they remain the dominant settlement type throughout the remainder of the prehistoric sequence in the region. Recall from Chapter Two that both Graybill (1981) and Johnson et al. (1989) suggested that changes (e.g., larger size and geographic constriction) in Ohio Valley village settlements that occurred in A.D. 1200 or 1250 were due to climatic deterioration. Although a cooler climate is not reflected in this model until A.D. 1350, temperatures had begun to decrease earlier; the net change was still relatively small at A.D. 1250 and summer temperatures were still warmer than average. It is likely, however, that climate change might have had an impact earlier in the northern part of the region. Thus, while that hypothesis is not disproved, supporting evidence is rather weak. Finally, recall that Richardson and Anderson (1999) attributed abandonment of the Upper Valley shortly after A.D. 1600 to severe drought episodes, and this correlation is supported by the climatic model.

In accounting for settlement reorganization that appears to correlate with climate, archaeologists rely on changes in carrying capacity resulting from conditions more or less favorable to plant productivity. For example, Dunnell and Greenlee (1999) noted that, at the beginning of the Late Woodland period, a warmer and wetter climate increased the net productivity of native cultigens, thereby making available sufficient calories to support nucleation where it was not sustainable earlier. This assumption that settlement reorganization was underlain by subsistence change needs to be addressed (particularly because it is the potential role of climate in subsistence variation that is of interest here). Researchers have

pointed out relative costs and benefits of different settlement options (see Greenlee 2001a and references therein), but it is clear that one basic threshold must be exceeded for any option to be sustained: a minimum number of calories/person/day throughout the annual cycle (Rafferty 1985). Because the people living in sedentary nucleated villages rely on a fraction of the territory available to those living in other settlement options (Fuller 1981), this requirement is a crucial one for them. Thus, there is good reason to believe that subsistence changes interacted with settlement reorganization.

VARIATION IN ISOTOPIC DIET

Figure 91 plots the stable carbon isotopic records for the Middle and Upper Valleys against the climatic model. For both areas, there is an apparent correlation between the appearance of the first significant maize consumers and warm, wet conditions ca. A.D. 900. Recall from Figure 90 that nucleated villages reappeared at this time, as well. Once established, the isotopic trajectories of the Middle and Upper Valleys appear to have remained flat (with Upper Valley populations tending to be more enriched than Middle Valley populations) until climate cooled at roughly A.D. 1350. Soon after, maize consumption decreased among populations of the Middle Valley, while it increased among populations of the Upper Valley.

VARIATION IN PLANT EXPLOITATION

Figure 92 shows the ubiquity of four taxa of plant remains (goosefoot, squash/gourd, maize and beans) in Late Woodland and Late Prehistoric assemblages against the climatic model. As described previously in Chapter Two, there is considerable variation in the composition of archaeobotanical assemblages. Although some of that variation may be correlated with climate, the poor representation of assemblages aged A.D. 700 – 900 makes that difficult to assess.

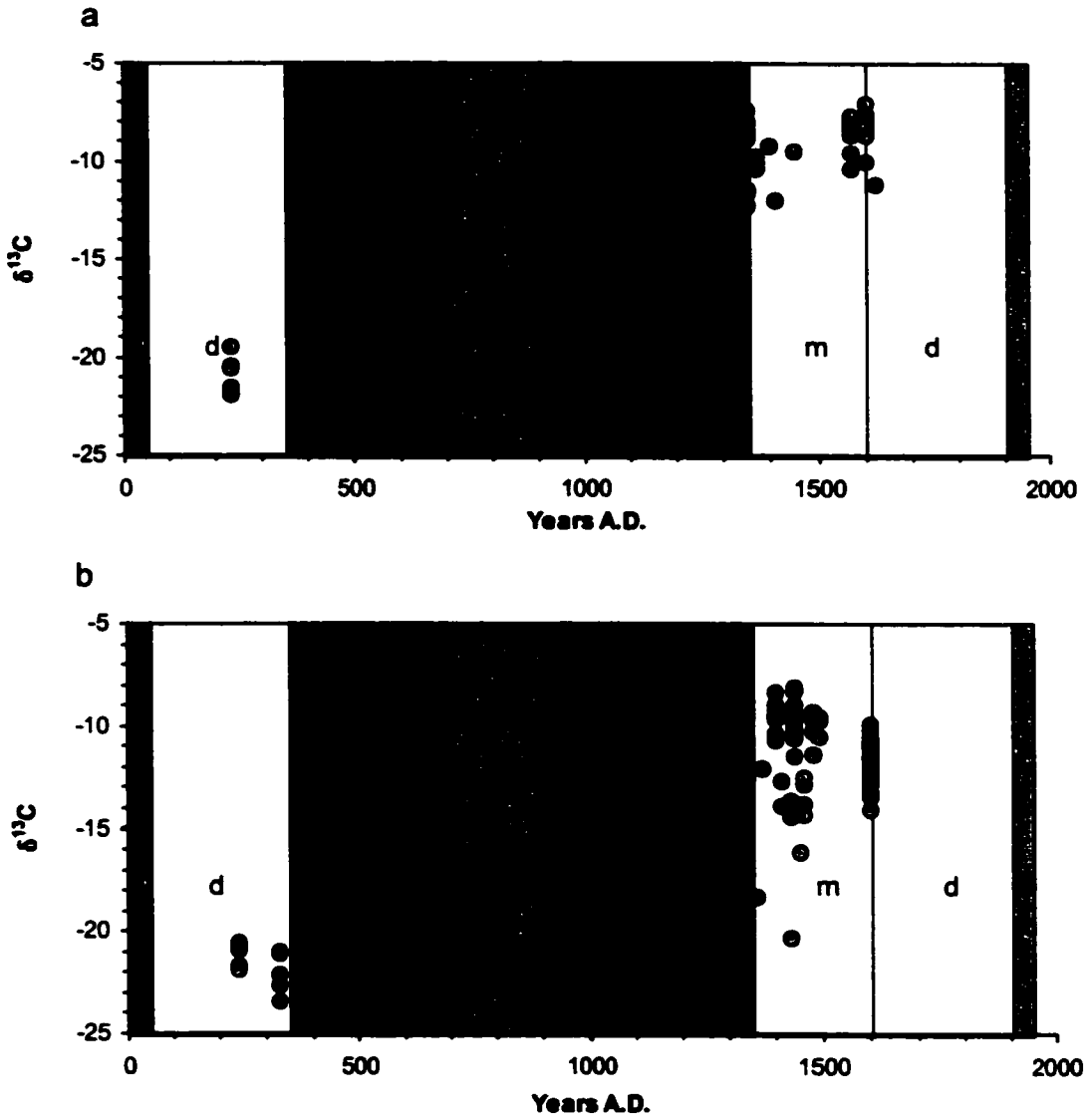


Figure 91. **Isotopic record of (a) upper (n = 83) and (b) middle (n = 351) Ohio Valley individuals versus the new climatic model.** Fill color indicates relative summer temperature (white = cool; gray = average; black = warm); letters indicate relative annual precipitation with d = dry and m = moist.

Recall from Chapter Two that archaeobotanical assemblages of the early Late Woodland period appear to reflect increased reliance on members of the EAC (particularly the starchy-seeded ones) squash/gourd over those of the Middle

Woodland period. The ubiquities of goosefoot and squash/gourd remains apparently decreased with climatic cooling and drying at A.D. 700, but the sample is inadequate. Interestingly, the ubiquity of goosefoot increases again ca. A.D. 1350, when climate again cools; the apparent decline in goosefoot exploitation during the latter part of the Late Woodland period was likely unrelated to climatic cooling.

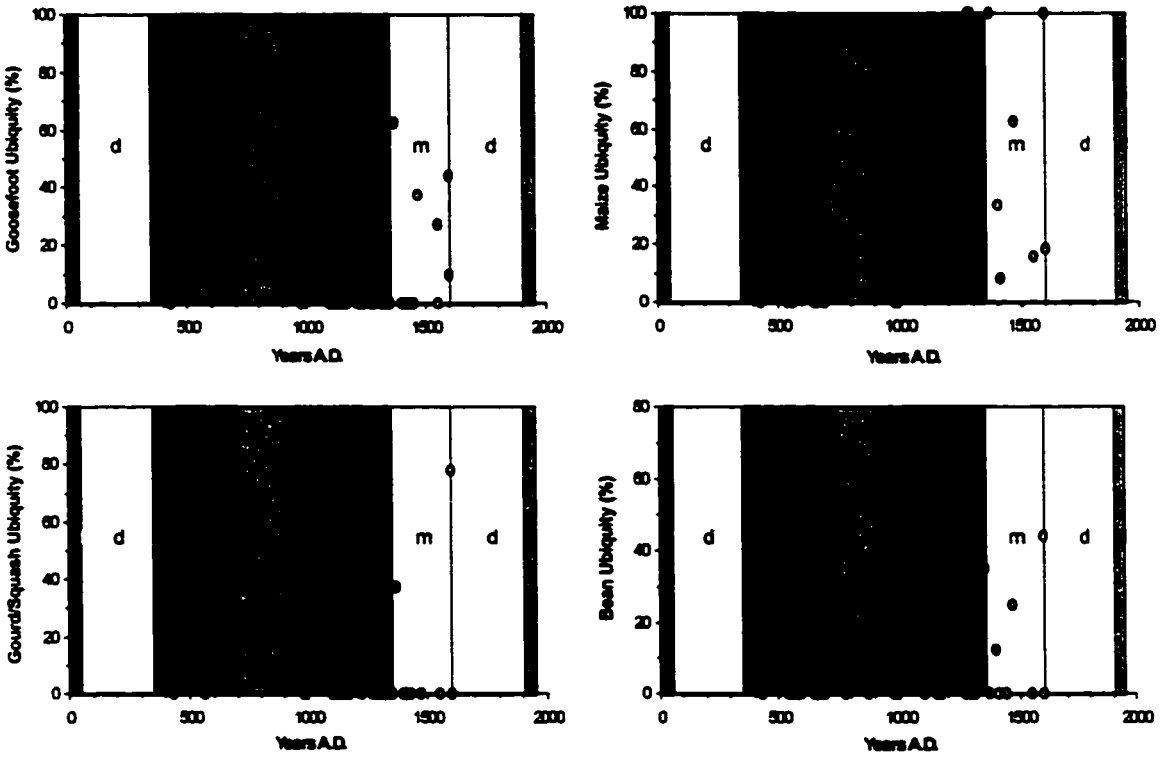


Figure 92. **Ubiquity of plant remains (goosefoot, gourd/squash, maize and beans) plotted against the new climatic model.** Fill color indicates relative summer temperature (white = cool; gray = average; black = warm); letters indicate relative annual precipitation with d = dry and m = moist.

Maize fragments occur significantly in one assemblage from A.D. 700 – 900 (Figure 92), but no bone was available for isotopic analysis there. Stable carbon isotope analyses of a handful of human bone samples dated to this climatic episode have failed to document significant maize consumption (Figure 91). Importantly, though, the bone samples came from nonresidential burial contexts

and thus they may represent a population distinct with respect to isotopic diet from the populations at locales where maize remains were found. The distribution of beans in archaeobotanical assemblages shows no correlation with climate.

BEYOND CORRELATION

Can climatic change account for the subsistence record of the Ohio Valley? There does appear to be some correspondence between climate, settlement and subsistence. The next step is to consider how varying selective conditions due to changing climate might have produced the subsistence changes documented.

Some of the EAC taxa that were apparently exploited most intensively during the warmer and wetter early Late Woodland (e.g., goosefoot) prefer wet habitats, but so do some that were neglected (e.g., sumpweed) (Asch and Asch 1978; Smith 1987, 1992a). Thus, subsistence change in the Late Woodland toward increased exploitation of particular resources cannot be explained simplistically by climatic change. It may be, however, that yields increased disproportionately among the different taxa. The relative impact of warmer/wetter climatic conditions on the yield of different taxa is not known, but recent observations document that goosefoot generally provides a higher gross yield than sumpweed, knotweed or sunflower (Smith 1987).

Similarly, given what we know of modern varieties of maize, maize yields should have increased under warmer and wetter conditions, as well. Smith (1987) implies that aboriginal maize yields may have only marginally surpassed those of goosefoot. However, he relies on maize yield data from the Upper Missouri during the 1860s and 1870s (Will and Hyde 1917), a time of severe drought in the upper Great Plains (Woodhouse and Overpeck 1998), and thus those data probably underestimate the productivity of that maize under more typical conditions. How yields for maize varieties of that time and place compare to those for Late Prehistoric maize in the Ohio Valley is, of course, unknown.

Given the above, it is probable that a change toward warmer and wetter conditions had a positive impact on plant productivity, while changes toward cooler and drier conditions had a negative one. Based on the modern climatic data, cooler and/or drier climatic episodes probably had a greater impact on resource productivity in the Upper Ohio Valley than elsewhere in the study area. Cooler climates almost certainly intensified the more extreme conditions (shorter, more variable growing seasons and cooler summer minimum temperatures) that characterize that area. In the Middle Valley, where modern data indicate less extreme conditions, cooler climates presumably had less severe impacts on resource productivity.

If the assumption that plant, particularly maize, productivity declined with cooling is correct, then what sorts of changes should we look for in the archaeological record? Under cooler conditions, populations that occupied landscapes or that had technologies which minimized the impact on subsistence should have had an advantage. For example, because of the way cold air drains, upland situations near slopes tend to be warmer and better protected from late spring and early fall frosts than bottoms (cf. Johnson 1998). Similarly, among bottomland situations, broad bottoms with sizeable terraces adjacent to large rivers are better protected from frosts than narrow bottoms. Technologically, the impact of frost can be reduced by planting crops in hills or ridges (Doolittle 1992; Riley 1987).

That Late Prehistoric settlements of the Upper Valley are biased toward upland situations has been noted; Johnson (1998), for example, has calculated that 56.6% of 422 recorded Late Prehistoric Monongahela occupations were located in upland settings. Such estimates may reflect a biased archaeological record, as Euroamerican activities probably destroyed archaeological evidence of many occupations along bottoms in the region before they could be recorded (cf. George 1974). Given this caveat, though, it is still useful to examine the

distribution of settings occupied with respect to changing climatic conditions. Under "good" warm and wet climatic conditions like those hypothesized to have dominated ca. A.D. 900 – 1350, upland and broad bottoms should be the most frequently occupied areas; under cold and wet conditions ca. A.D. 1350 – 1600, bottoms should comprise a smaller proportion of the occupied settings, with narrow bottoms being particularly poorly represented; and, with cold and dry conditions ca. A.D. 1600 – 1900, moister soils may have given broad bottom situations a slight advantage over upland situations.

Figure 93 shows the locational distribution of dated occupations in my Upper Valley sample across age classes drawn from the climatic model. It is important to remember that this sample was chosen to include all locales with published subsistence data and/or human skeletal remains available for chemical analysis; there is a strong potential for uncontrolled bias with respect to settlement

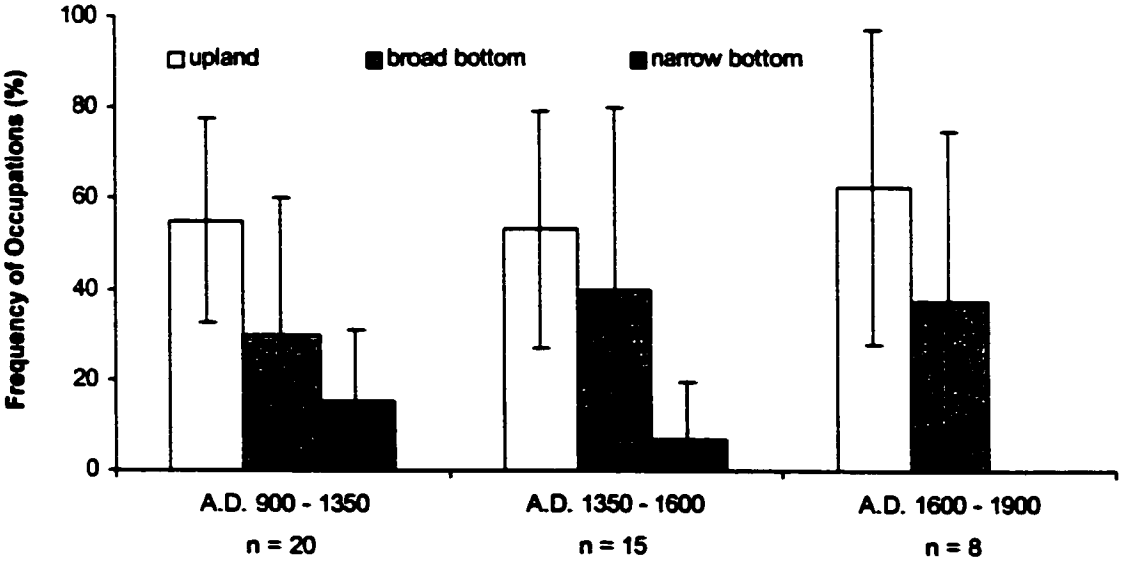


Figure 93. **Relative frequency of occupations in upland, broad bottom and narrow bottom settings during the three different climatic episodes presented in the climatic model.** Error bars indicate 95% confidence intervals. Settlement location data in Appendix B.

options. Clearly, the overall proportion of occupations in upland settings (55.8%) in my sample is very close to the estimate of Johnson. As the 95% confidence intervals indicate, however, sampling error could account for much of the apparent patterning. Although there is no clear evidence for an increased use of upland situations through time as climate deteriorates, the frequency of occupations in narrow bottoms apparently does decrease over time.

Johnson (1998) has indicated that the distribution of Upper Valley settlements became more constricted geographically with deteriorating climate ca. A.D. 1250. After that time, settlements were more frequently found in areas with longer frost-free seasons. Figure 94 shows the geographic distribution of Upper Valley occupations in my sample during the three climatic episodes. There is an apparent contraction accompanied by westward and northward shifts in the territory occupied after climate cooled; occupations are located in areas with mean frost-free season lengths greater than 145 days. Interestingly, though, occupations within the last, cool and dry, climatic episode show an expanded distribution,

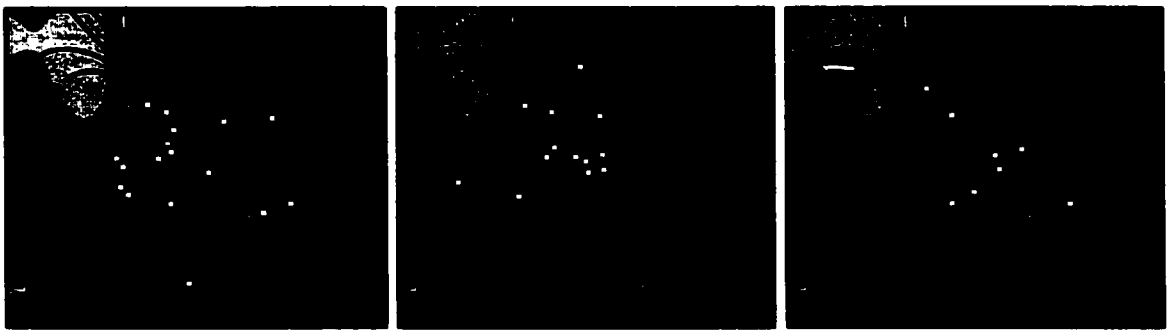


Figure 94. **Geographic distribution of Upper Valley occupations during different climatic episodes.** From Figure 82, isolines indicate mean modern frost-free season in days; shading indicates associated standard deviations (light fill = small SD; dark fill = large SD). Left, distribution of occupations during warm and wet conditions, A.D. 900 – 1350; middle, distribution of occupations during cool and wet conditions, A.D. 1350 – 1600; right, distribution of occupations during cool and dry conditions, A.D. 1600 – 1900.

particularly toward the south into areas of less variable, but relatively short, frost-free season length. It would seem that the geographic distribution of the last prehistoric occupations of the Upper Valley cannot be explained entirely by mean climatic conditions (cf. Johnson 1998).

Different trajectories of subsistence change are likely outcomes of climatic variation under different circumstances. The isotopic record indicates that trends in maize consumption during the Late Prehistoric period differed for populations of the upper and middle Ohio River valleys. This is not unexpected, given the greater impact that a cooler climate would have had on growing season conditions in the Upper Valley. Turning now to a consideration of the particular trajectories, it is noteworthy that isotope measurements on individuals from the Upper Valley, generated for this research, play a critical role in this analysis.

Dietary commitment to maize increased in the Upper Valley at the end of the Late Prehistoric period (Figure 91a). Since the diets of individuals living in narrow bottom/upland and broad bottom situations differ, apparently reflecting variation in the local ecology, and since climatic change is likely to affect the productivity of different topographic settings differently, it makes sense to consider those two groups separately. A boxplot showing the structure of $\delta^{13}C$ values (Figure 95) for the Upper Valley during the three climatic episodes of interest indicates increasing enrichment over time for upland populations. Indeed, a one-way ANOVA indicates that $\delta^{13}C$ values for individuals living in upland settings differed significantly across the different climatic episodes ($F = 9.038$; $p < .001$). The same cannot be said for individuals living in broad river bottom situations ($F = .063$; $p = .803$), but there are no individuals from the final climatic episode in my sample. Interestingly, though, variation in the isotopic diet of bottom populations appears to increase as climate cools.

In contrast to the Upper Valley isotopic record, $\delta^{13}C$ values in the Middle Valley appear to decline soon after a cooler climate prevails (Figure 91b).

Earlier in this chapter, I noted that one hypothesis for the high incidence of relatively-depleted (< -15 ‰) individuals from Late Prehistoric contexts in southwest Ohio involved the greater frequency of summer droughts in the area. In particular, I speculated that the lower dietary commitment to maize represented by depleted $\delta^{13}C$ values may have been selected for by greater variation in maize crop yields produced by frequent summer droughts. The implications of this hypothesis are that, if true, then a climatic change toward cooler and moister conditions should

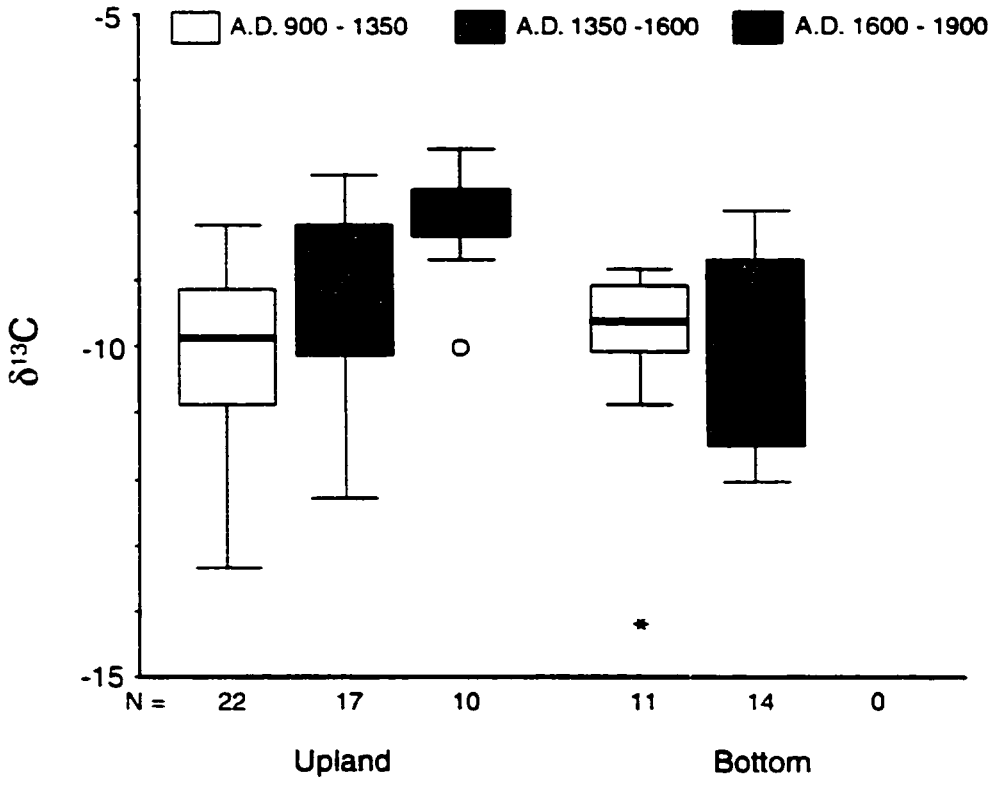


Figure 95. **The structure of $\delta^{13}C$ values for Upper Valley populations from upland and broad bottom situations over different climatic episodes.** The O indicates an outlier (> 1.5 box lengths); the * indicates an extreme value (> 3 box lengths). Individuals from narrow bottom settings (n = 5) are excluded.

have reduced the frequency of summer droughts, thereby changing the selective conditions such that populations consuming more maize would have had an advantage; there should have been more individuals with enriched $\delta^{13}C$ values and fewer relatively depleted ones. As the climate became drier ca. A.D. 1600, droughts probably increased again in frequency and/or severity, and the trend in isotopic diet would have reversed itself; there should be a decrease in the numbers of enriched individuals.

Isotopic measurements on samples from southwest Ohio are available for only the first two climatic episodes (A.D. 900 – 1350, warm and wet; A.D. 1350 – 1600, cool and wet) and they are heavily weighted toward the first episode, but they do not meet the derived expectations. In fact, they show the opposite pattern. Diet during that episode of warmer and wetter conditions (mean ± 1 SD = -11.640 ± 3.351) was *more* enriched than during the subsequent cool and wet period (mean ± 1 SD = -15.460 ± 3.161) and a *t*-test indicates the difference is significant at $\alpha = .05$ ($t = 2.731$; $p = .007$). Although this is a limited test, it does not support the hypothesis that drought was a factor in levels of prehistoric maize consumption in southwest Ohio.

Like in the Upper Valley, isotopic diet differs between topographic settings among Middle Valley populations. Figure 96 shows, for broad and narrow bottom settings, the structure of isotopic variation among Middle Valley populations. The plot shows different trajectories within the two settings, although the narrow bottom setting is represented by a small sample. For each setting, a Levene's test for homogeneity of variance indicates significant differences in variance among individuals from different climatic episodes (broad bottoms: $F = 6.373$, $p = .002$; narrow bottoms: $F = 42.973$, $p < .001$). Thus, ANOVA is not an appropriate statistic for determining the significance of differences between groups.

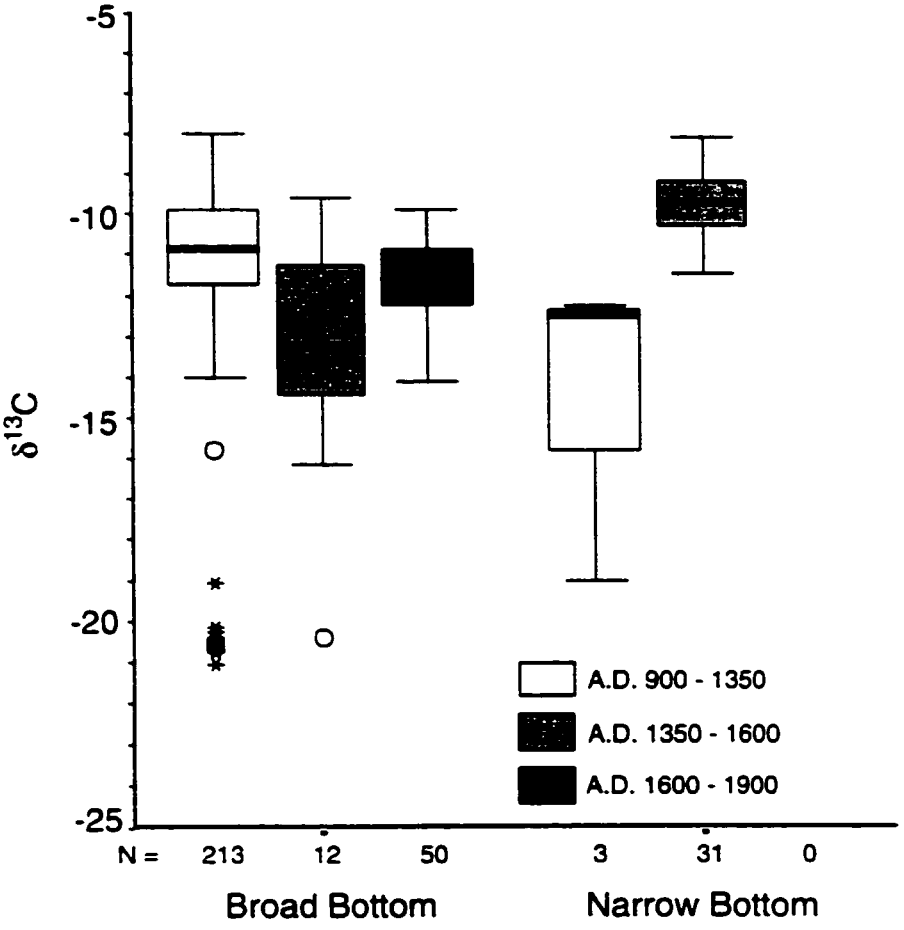


Figure 96. **Structure of $\delta^{13}C$ values for Middle Valley individuals from broad and narrow bottom situations during different climatic episodes.** The Os indicate outliers (> 1.5 box lengths); the *s indicate extreme values (> 3 box lengths). Individuals from upland settings (n = 2) are excluded.

Kruskal-Wallis tests indicate significant differences in diet between the climatic episodes – the individuals do not come from the same dietary population for either situation (broad: $\chi^2 = 20.945$, $p < .001$; narrow: $\chi^2 = 7.993$, $p = .005$). Removing the depleted ($\leq$ - 15 ‰) individuals, which affects primarily the first climatic episode (but importantly does not change significantly the overall structure of data as shown in Figure 96) does not change these conclusions (broad: $\chi^2 = 33.106$, $p < .001$; narrow: $\chi^2 = 5.487$, $p = .019$). Notably, changes in isotopic diet

among individuals from broad bottom settings do not conform to simple intuitive predictions about maize production and climate. From this, maize consumption appears to be the least during the climatic episode when maize productivity might have been the greatest.

CONCLUSIONS

In this examination of the subsistence records of the middle and upper Ohio River valleys with respect to environmental and climatic variation, particular emphasis was placed on examining the possible roles of environment and climate in the varying pathways of dietary change associated with maize farming. It is not surprising, given the outcomes of previous efforts, to find a significant local physiographic effect on maize-based subsistence systems. In general, populations living in uplands and/or narrow valley bottoms tend to have consumed significantly more maize than those living in broad valley bottom settings. One reason for this might be that broad valley bottoms tend to have a greater range of microhabitats that cover a greater area than in other settings, thus providing a richer, more diverse resource base to exploit. Given the negative fitness consequences of a heavy commitment to maize (Farrow 1986), a more varied diet would be selectively advantageous when it could be economically maintained.

My evaluation of climate as a factor in accounting for variation in the archaeological record relied on a regional model of climatic change derived from distantly-located and/or poorly-resolved climate proxy records. Clearly, a better approach is needed. Given its geology, the Ohio Valley is unlikely to produce a suite of well-preserved, locally-relevant pollen and/or dendroclimatological assemblages upon which to draw. One potential solution involves isotopic analysis of animal and plant remains from relevant archaeological assemblages (e.g., Marino and DeNiro 1987; Stephan 2000; Stuart-Williams and Schwarcz 1997; White 1989). With better climatic data, it would be easier to move beyond coarse-grained correlations in the

timing of climatic and subsistence change to consider how climate might, in an ultimate sense, cause subsistence change.

From the scanty archaeobotanical data available, it seems unlikely that climatically-induced increases in net productivity alone can account for intensified exploitation of indigenous cultigens during the early part of the Late Woodland period. To resolve ambiguity over the potential role of climate will require a larger sample of archaeobotanical assemblages, along with more localized and more precise climatic reconstructions. Changes in the tools, techniques or schedule of exploitation or in characteristics of the plants themselves (e.g., maturation, harvestability or storability) may provide necessary aspects of an explanation.

The isotopic record of maize consumption shows a significant increase in consumption that appears to correspond with warmer and wetter conditions ca. A.D. 900. The archaeobotanical record, though, suggests the correlation may be an artifact of sampling. Additional samples from late Late Woodland contexts are clearly required. Beyond that, climate remains a factor in explaining the trajectories of Late Prehistoric isotopic diets of middle and upper Ohio Valley populations. Climatic change would have had varying impacts on the productivity of wild and cultivated plants across the study region and the subsistence record appears to reflect varying selective conditions. It is important to note that, while climate has not been ruled out as a factor in explaining some aspects of the subsistence record, there may be other parameters at work. Other hypotheses remain to be tested.

CHAPTER SEVEN: DEMOGRAPHY

From an evolutionary perspective, the main thrust of the "population pressure" hypothesis for explaining the appearance and spread of maize farming is that a change in selective conditions due to a local increase in the number of consumers favored subsistence change toward maize farming and consequently those individuals who consumed significant levels of maize increased. As noted earlier, though, this scenario probably transposes those two processes. Once specialized farming systems were established, local population size and/or density may have been critical variables in determining the subsistence trajectories for different areas. The fact remains that key elements of the scenario used to support "population pressure" arguments (i.e., population size, resource depletion, intergroup competition, and cooperation) remain largely assumptive, poorly documented, and/or undefined.

EVIDENCE FOR CHANGE IN THE NUMBER OF CONSUMERS

Archaeologists generally turn to one or more data sets to evaluate changes in the number of consumers exploiting the resource base in a study region. They look at the number of archaeological settlements occupied in the area at a given time, the size of those settlements and the roofed living area within settlements. The sample used in this study is clearly inadequate for examining changes in the number of settlements. Indeed, archaeological research has been biased against small dispersed settlements, prohibiting a clear examination of changes in settlement numbers in the study region at the crucial time during the latter part of the Late Woodland period.

Although the settlement record may be reasonably well-documented for some specific areas, published reports typically do not distinguish the age of

occupations beyond time period (e.g., Middle Woodland, Late Woodland, or Late Prehistoric). In such cases, that there are more and/or larger settlements that belong to the Late Prehistoric period does not allow one to address the problem of when and, consequently, why the implied population increase happened. One exception, based on archaeological surveys conducted throughout Dearborn, Ohio and Ripley counties in southeast Indiana (Figure 97), is provided by Reidhead (1981). Reidhead identified similar settlement patterns for Late Woodland and early Late Prehistoric occupations of the area. He noted that there was evidence for later population growth, in the form of more and larger settlements, during the Late Prehistoric period. Thus, he argued that population increase occurred during the Late Prehistoric period, not during the Late Woodland period or at the "transition" between the Late Woodland and Late Prehistoric periods.

Even without settlement counts, settlement size provides one way to estimate, on an ordinal scale, local population size. This, of course, only works if one is dealing with a single type of settlement system, i.e., nucleated and dispersed settlements cannot be compared. Figure 98 arrays temporal variation in settlement size for nucleated sedentary locales against $\delta^{13}C$ values. The two data sets intersect for most, but not all, points (i.e., there are settlements lacking individuals with $\delta^{13}C$ data and vice versa). Based on this sample of settlements, there is no evidence for an increase in the number of consumers/settlement *prior to* the increase in maize consumption ca. A.D. 900. The Hansen site, a large buried Late Woodland deposit located in northeastern Kentucky (Figure 97), represents the only possible exception to this observation, but it is not likely that the entire area was occupied contemporaneously (Ahler 1987, 1988). The apparent conclusion is that large Late Prehistoric settlements follow the timing of significant maize consumption by roughly 300 years. Other analyses have found settlement size to increase through time during the Late Prehistoric period (Graybill 1981; Reidhead 1981).

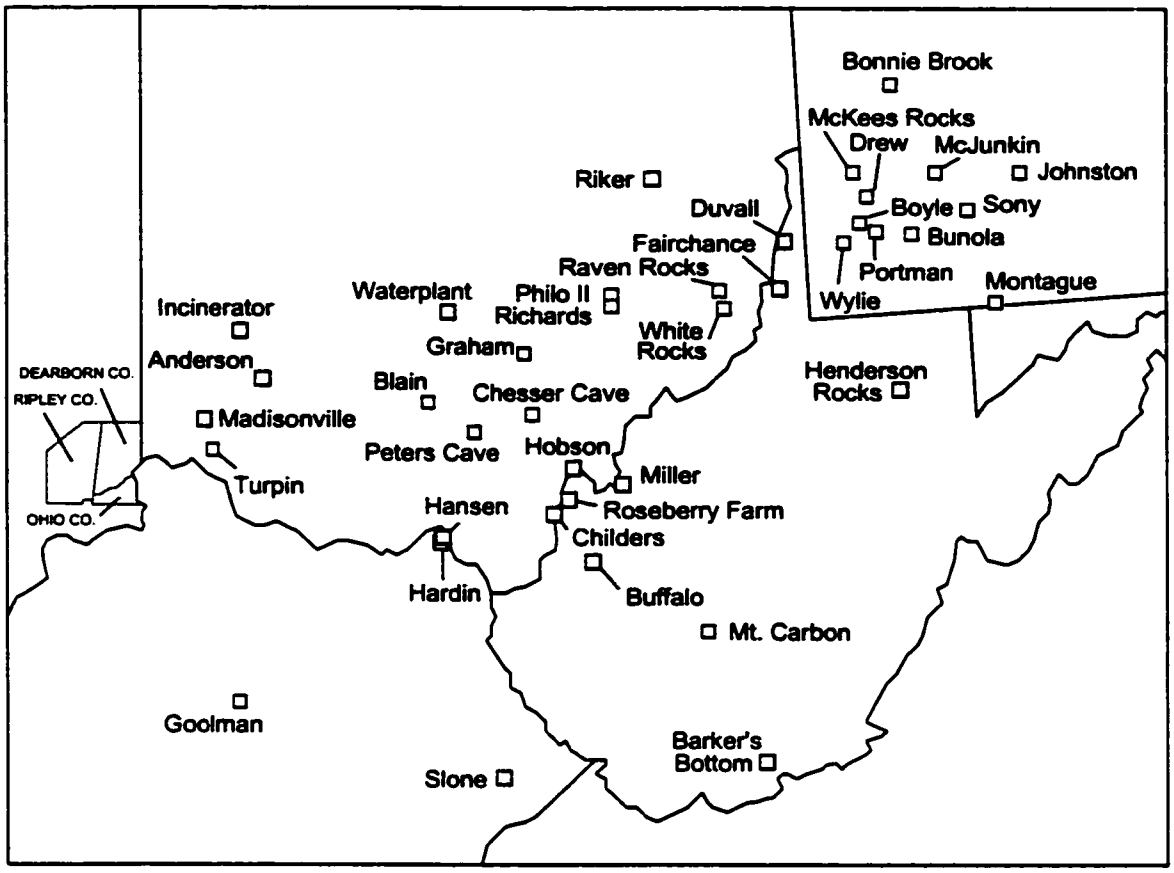


Figure 97. Ohio Valley locales mentioned in the text of this chapter and/or indicated in tables or figures.

The amount of "roofed area" within settlements is the last proxy of population that I consider. Since most locales are incompletely excavated, the amount of roofed area had to be estimated crudely. For settlements where individual structures could be identified and measured, the proportion of roofed area to the area excavated was calculated and scaled upward proportionate to the total size of the locale. These estimates are necessarily crude because they assume that the amount of roofed area in the excavated area was representative of that over the entire settlement and that there is no size-dependent change in settlement organization. Rather than using roofed area to estimate the number of individuals occupying the settlement (a la Naroll 1962), I use these data as an ordinal measure of population size.

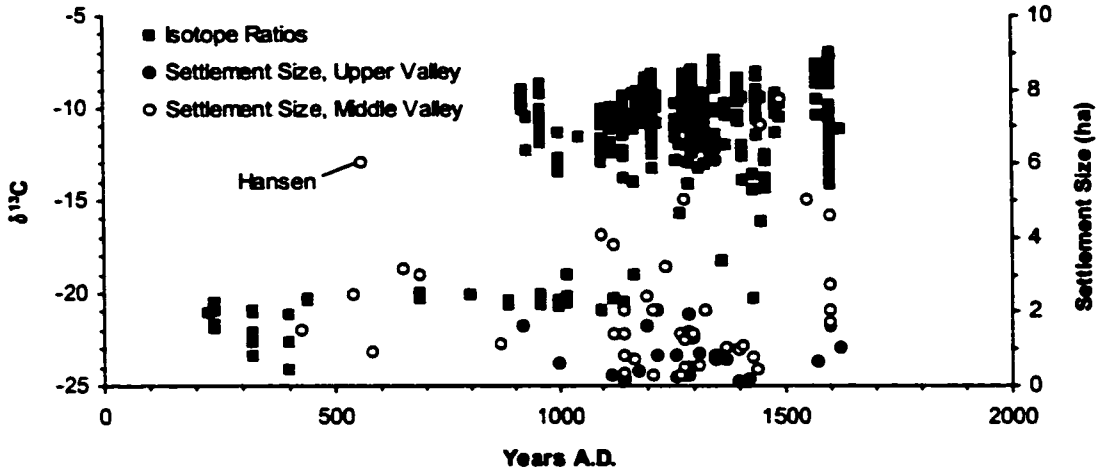


Figure 98. **Settlement size of Ohio Valley nucleated sedentary villages and the record of isotopic diet.** Size data presented in Appendix B.

Figure 99 shows temporal variation in estimated roofed area for nucleated sedentary locales against $\delta^{13}C$ values. Unfortunately, the sample of locales with sufficient information with which to estimate roofed area is really inadequate for the problem at hand. In particular, crucial data are lacking for the latter part of the Late Woodland period and the roofed area estimates for two early Late Woodland samples are questionable. First, like the settlement size estimate, the roofed area estimate for the Hansen locale probably combines data from at least two temporally-distinct occupations at that locale. Second, the roofed area estimate for Waterplant, a Late Woodland settlement located near Columbus, OH (Dancey 1988), is the summed area of high-density artifact clusters visible in the plowzone (and is not delimited by postmolds like other estimates). It is thus possible that what has been measured is the size of localized sheet middens unrelated to houses, and, if that is the case, almost certainly covering a larger area. If the Waterplant estimate is accurate, then there is no evidence for population increase until the latest Late Prehistoric period. That is not consistent with the previously-reviewed settlement evidence. If the Waterplant estimate is too large, then larger population sizes appear to follow evidence for maize farming by roughly 250 years; the lack of

late Late Woodland samples is a critical problem, but this observation is consistent with other settlement evidence.

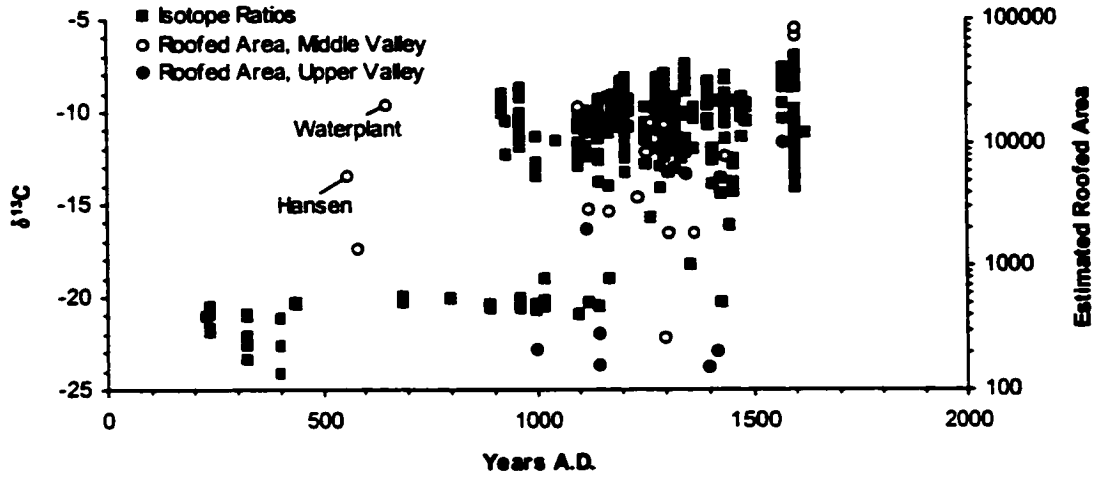


Figure 99. **Estimated roofed area (m^2) of Ohio Valley nucleated villages and the record of isotopic diet.** Area data in Appendix B.

ASSESSMENT OF RELATIVE FERTILITY RATES

The ratio of children to old adults in age-at-death distributions has been argued to be a reliable indicator of relative fertility rates (Milner et al. 1989; Sterling 1999). When the ratio is low, fertility is low; when the ratio is high, fertility is high. Modern ethnographic populations appear to support this observation. Thus, Milner et al. (1989) modeled age-at-death schedules for the !Kung (as representative of populations with relatively low fertility) and for the Yanomamo (as representative of those with relatively high fertility) for purposes of comparison with archaeological assemblages.

The first step in assessing relative fertility rates from archaeological skeletal assemblages requires determining if and how they are biased. Comparing the age structure of archaeological skeletal assemblages with models derived from modern populations is one route to such an assessment (Konigsberg 1985; Milner et al. 1989; Paine and Harpending 1998). In Figure 100, age-at-death distributions for

several Ohio Valley archaeological assemblages are plotted with those from two ethnographic populations, the !Kung and the Yanomamo. The archaeological assemblages are arranged in temporal order from earliest (Montague) to latest (Hardin); it is particularly unfortunate that no published data are currently available on the age structure of large Late Woodland skeletal collections (e.g., Zencor, Turpin). Only three assemblages, Montague, Incinerator and Hardin,

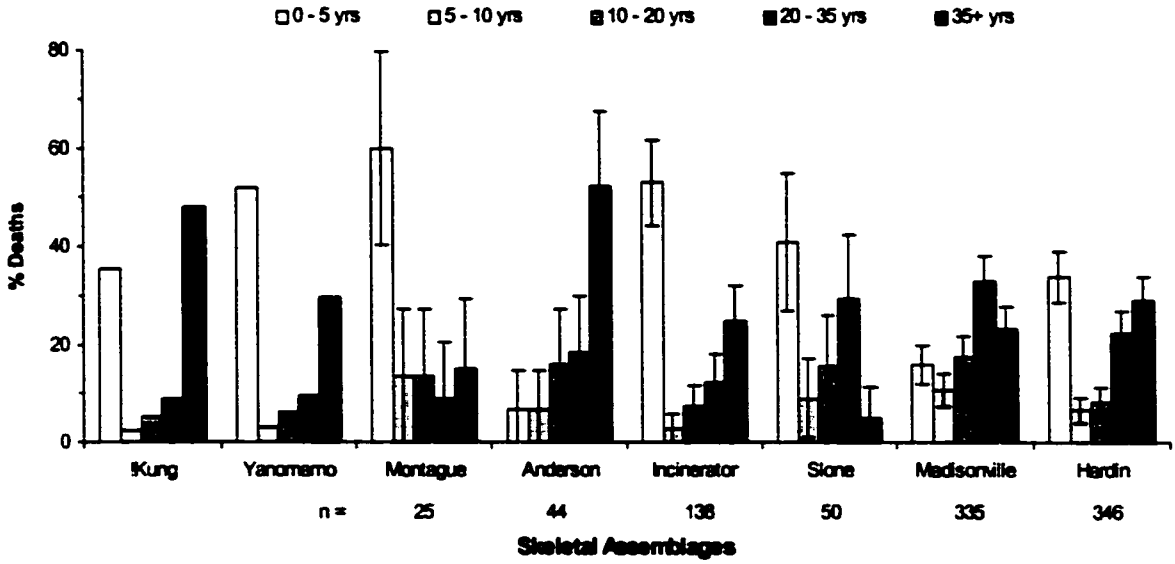


Figure 100. **Age-at-death distributions of the !Kung and Yanomamo models and Late Prehistoric skeletal assemblages from Ohio Valley locales.** Data for several assemblages have been retabulated to match the age divisions of other samples. Error bars indicate 95% confidence intervals.

approximate the ethnographically-expected distributions. In the Anderson and Madisonville assemblages, children tend to be underrepresented and/or young/middle-aged adults tend to be overrepresented, indicating that a sampling problem is likely.[38] In the Slone assemblage, the deficiency lies in the > 35 yr age class, a pattern less easily explained as sampling error.

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[38] In some cases, this may be due to preservation and, in others, to a combination of differential burial treatment and sampling. In some parts of the Eastern

Figure 101 shows more clearly how Montague and Incinerator are most similar to the Yanomamo age-at-death model, while Hardin is more similar to the !Kung model. The comparisons suggest that fertility rates may have been high early within the Late Prehistoric period, as might be expected following the incorporation of a productive staple crop into those populations' subsistence systems. The last comparison, that the late Late Prehistoric population at Hardin may have experienced relatively low fertility rates, makes sense since, by that time, selective conditions in the Ohio Valley were significantly different. Not only were populations greater overall after centuries of maize agriculture, but also lower reproductive rates might have been favored by the impacts of a cooler and

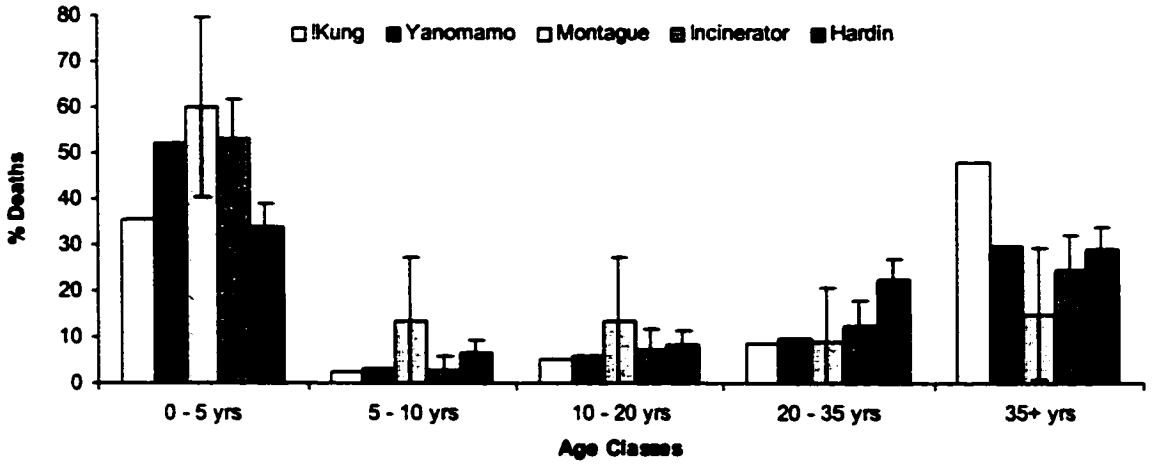


Figure 101. **Comparison of age-at-death distributions between the !Kung and Yanomamo models and three archaeological assemblages.** Archaeological skeletal assemblages are from the Montague (early Late Prehistoric), Incinerator (middle Late Prehistoric) and Hardin (late Late Prehistoric) locales. Error bars indicate 95% confidence intervals.

Woodlands, including the upper Ohio Valley, adolescents were interred in houses and adults were buried in cemetery areas within villages (Butler 1939; Dunnell, p.c.). That the burial assemblage from Montague, an Upper Valley locale, is apparently unbiased is probably due to the nearly complete excavation of that village.

increasingly drier climate; that late in prehistory, the introduction of Old World diseases and competition with northeastern groups may have also affected fertility. Indeed, the combined effects of disease and trauma may account for the higher-than-expected proportions of young/middle-aged adult deaths at Hardin.

SUMMARY

Although the data are poor, there is currently no evidence for a significant increase in the number of consumers prior to the appearance of maize farming. Instead of serving its usual explanatory role as a cause for subsistence specialization, population increase appears to have been a product of that subsistence change. Local populations appear to have increased substantially during the Late Prehistoric period, following the appearance of maize farming in the region.

RESOURCE DEPLETION

One consequence of an increase in the number of local consumers could be a decrease in the availability of resources that provided high net returns. In response to reduced availability of high net-returning resources, consumers may exploit more lower net-returning ones than they otherwise might. There are several ways that this phenomenon might be evidenced: by an increase in the richness and/or the evenness of faunal and/or botanical assemblages; by a decrease in the ratio of high:low net-returning classes of taxa; by decreases in the mean animal body size captured; and by human undernutrition, which may occur as a consequence of a reduction in the quantity and/or quality of exploited resources.

ASSEMBLAGE RICHNESS

In the face of a reduction in the availability of highly-ranked (high net-returning) resources, predators may expand their diet to include ones of lower

rank. If so, the number of resources exploited (subsistence breadth) may increase. Accordingly, sample richness is sometimes used as a measure of maximum subsistence breadth (Broughton and Grayson 1993; Grayson and Delpech 1998).[39]

When richness is measured as the number of genera of charred seeds identified, there is a negative, and not statistically significant, correlation (ρ = -.182; p = .443) between richness[40] and sample age (Figure 102). When Late Woodland and Late Prehistoric assemblages are compared using a Mann- Whitney test, they differ significantly in the number of genera present (U = 17.000; p = .024). As a group, the later assemblages have fewer plant genera than the earlier ones; with few exceptions (primarily maize and beans), later archaeobotanical assemblages are subsets of the earlier ones. Among the plant data, at least, there is no evidence for an expansion of plant resource exploitation prior to the appearance of maize farming.

Figure 103 shows the relationships between the number of vertebrate genera and sample size for middle and upper Ohio Valley assemblages. Neither the regression slopes nor the elevations[41] differ between the two datasets (Table 6); they can be concluded to sample the same population. The correlation between the number of genera and (Log_{10}) NISP is highly significant (ρ = .796; p < .001), consistent with a strong sample size effect on faunal richness.

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[39] This is not without problems. Several factors, including sampling, mechanical, and behavioral processes, may influence assemblage richness (Grayson and Delpech 1998).

[40] There is no significant correlation between the number of genera and NISP (ρ = .259; p = .270) after three very small samples (Barker's Bottom, Augusta and Laughlin) have been removed from consideration; thus, sample size does not appear to control sample richness.

[41] Comparing elevations is roughly equivalent to comparing y-intercepts, but does not require extrapolation beyond the range of x values that comparing the latter would require (Zar 1984).

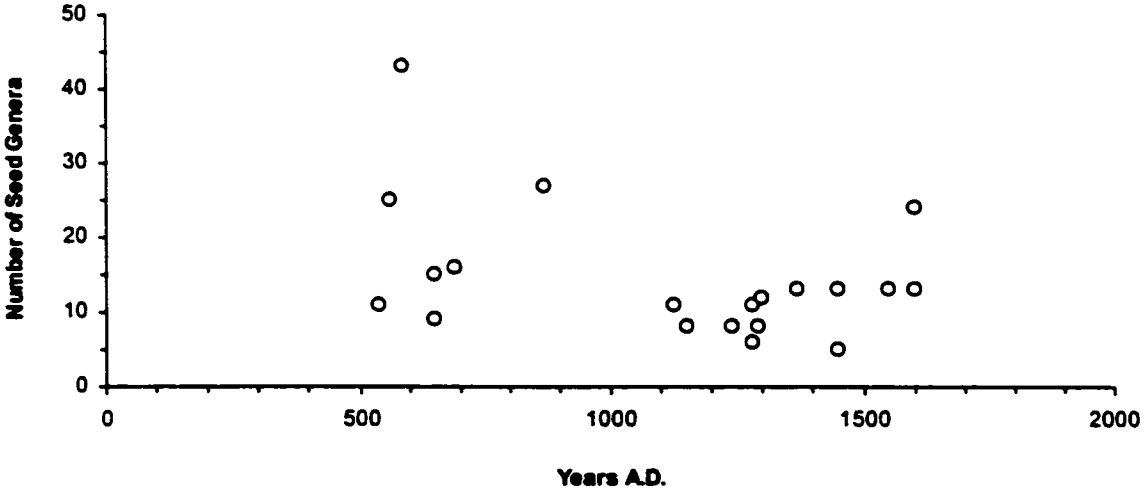


Figure 102. **Temporal variation in richness of charred seed genera in Ohio Valley archaeobotanical assemblages.** Data are in Appendix B.

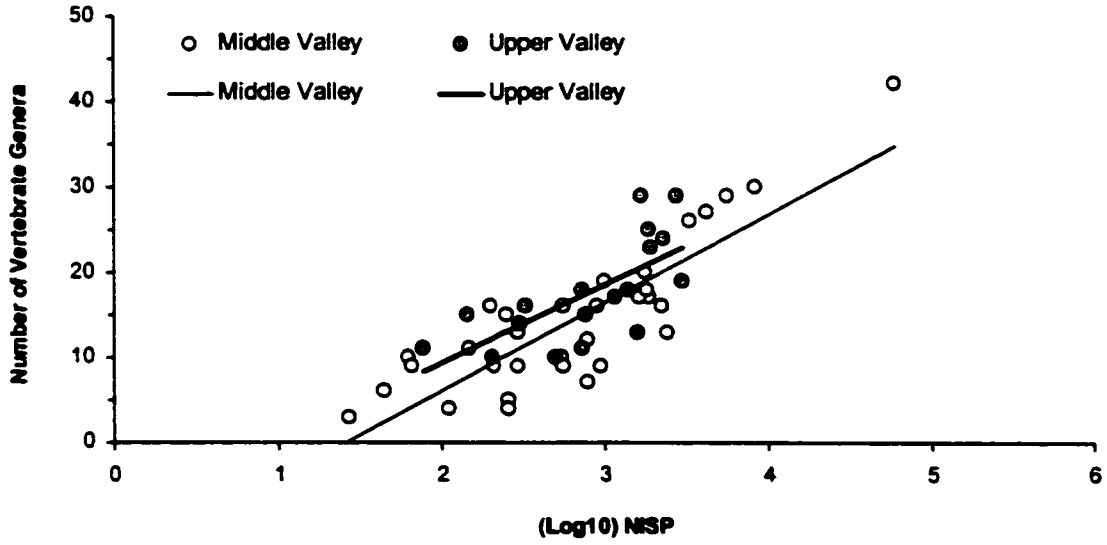


Figure 103. **Relationships between vertebrate faunal genera and (Log_{10}) NISP for middle and upper Ohio Valley assemblages.** Data are in Appendix B.

Table 6. Comparison of the sample size:richness/evenness relationships between the Middle and Upper Valleys for three different faunal classification systems.

Classification	Regression Slope		Regression Elevation	
	t^a	p	t^b	p
Richness (n classes):				
Vertebrate Genera	-1.180	$.50 > p > .20$	-1.556	$.20 > p > .10$
Resource Acquisition	-1.402	$.20 > p > .10$	-1.246	$.50 > p > .20$
Habitat Preference	-1.381	$.20 > p > .10$	-1.352	$.20 > p > .10$
Evenness (J'):				
Vertebrate Genera	-.9299	$.50 > p > .20$	-.6853	$.50 > p > .20$
Resource Acquisition	-.4027	$p > .50$	-.2337	$p > .50$
Habitat Preference	-.2222	$p > .50$	-.0597	$p > .50$

[a] $t_{.05(2),46} = 2.013$

[b] $t_{.05(2),47} = 2.012$

One way to minimize the impact of sample size on richness might be to reaggregate vertebrate genera into fewer classes. Certainly, there is no necessary relationship between scientific taxonomic classes (genera or species) and classes of resource exploitation. The Linnaean taxonomic system, built to systematically and hierarchically classify relationships among organisms (Panchen 1992), has little relevance to the problem of assessing variation in resource exploitation. Resource classes[42] that track different habitats and/or resource acquisition technologies are potentially more useful, even if they are probabilistic. Two different classification systems, one reflecting resource acquisition technology (Neusius 1986) and the other reflecting preferred faunal habitats (Greenlee 2002), are used here (Table 7).

[42] In the parlance of behavioral ecology, the resource acquisition and habitat preference classification systems define different resource "patches" (Broughton 2001; Charnov 1976).

As with the generic classification, the sample size:richness relationships for the two resource classification systems do not differ between the Middle and Upper Valleys (Table 6). Since the Middle and Upper Valley assemblages appear to sample the same population, assemblages from the two areas can be combined analytically. For both classification systems, the number of classes is correlated positively and significantly with (Log_{10}) NISP (resource acquisition: ρ = .659, $p < .001$; habitat preference: ρ = .640, $p < .001$). Richness of faunal assemblages is thus a doubtful indicator of subsistence richness and it will not be examined further.

Table 7. Faunal resource classifications. Faunal taxa are aggregated into resource classes based on aquisition technology (Neusius 1986) and habitat preference (Greenlee 2002). See Appendix B for taxonomic composition of classes.

Acquisition Classification	Habitat Preference Classification
Waterfowl	Birds, aquatic/semi-aquatic
Turkey	Birds, secondary/forest edge
Other birds	Birds, mature woodland
Aquatic mammals	Birds, prairie/grassland
Domestic dogs	Mammals, aquatic/semi-aquatic
Deer	Mammals, secondary/forest edge
Raccoon	Mammals, mature woodland
Squirrel	Mammals, prairie/grassland
Other mammals	Commensal animals

ASSEMBLAGE EVENNESS

One consequence of expanding the resource base to compensate for decreased availability of high net returning resources might be an increase in the evenness of resource use (Grayson and Delpech 1998; Grayson et al. 2001). Thus, if resource depletion preceded the appearance of maize farming, there should be evidence for increasing evenness in the Late Woodland period. The equitability

index[43] (Lincoln et al. 1998; Pielou 1966; Zar 1984), a measure of evenness that corrects for the number of classes, is used here. Since calculating the equitability index (J') for each assemblage relies on proportions of different taxa, evenness is examined for faunal resources only.

Because evenness, like richness, is also susceptible to sample size problems, its relationship with ($\log_{10}$) NISP is examined. Again, the slope and elevation of regression equations for Middle and Upper Valley assemblages are compared (Table 6); the two datasets do not differ for any of the classification systems. The relationship between evenness and sample size is significant for the generic classification (ρ = -.387; p = .006), but it is not significant for the resource acquisition (ρ = -.146; p = .313) or the habitat preference (ρ = -.214; p = .136) classifications. Since the distributions of the latter two classification systems are apparently not influenced by sample size, they warrant further consideration.

Resource Acquisition Classification

The resource acquisition classification system was designed to correspond to different technologies that might be required to exploit various faunal taxa (Neusius 1986). Evenness values thus reflect the relative proportion with which these exploitation technologies are represented in assemblages. When evenness is compared among assemblages with different levels of preservation (Appendix B), preservation appears to have a significant impact on assemblage evenness (χ^2 = 11.668; p = .009). Removing the five assemblages with poor preservation (Childers, Goolman, Hansen, Portman and Wylie) eliminates this relationship (χ^2 = 1.021; p = .600) and thus they are removed from the following

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[43] The equitability index is calculated as $J' = H' \div ((\log_{10})C)$, where C is the number of classes and H' is the Shannon-Weiner Index of diversity ($H' = -\Sigma(p_i)((\log_{10})p_i)$, where p_i is the probability that a specimen belongs to class i). Higher values of J' indicate greater evenness in the proportions of classes, whereas lower values indicate that proportions of some classes are higher/lower than others.

analysis. Evenness does not differ significantly among assemblages collected using different recovery techniques ($\chi^2 = 3.256$; $p = .196$).

Figure 104 plots the trajectory of J' as calculated using the resource acquisition classification for the Ohio Valley faunal assemblages. Interestingly, the Middle and Upper Valleys present different trajectories in the structure of resource exploitation. A previously identified trend toward decreasing variance in evenness of faunal exploitation among Middle Valley assemblages[44] during the period A.D.

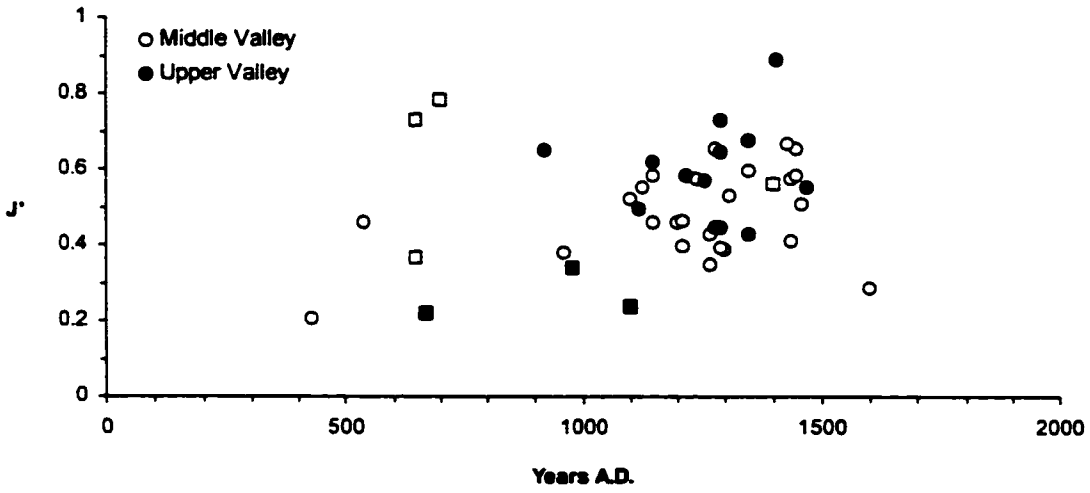


Figure 104. **Equitability index (J') as calculated using the resource acquisition classification derived from Neusius (1986).** □, seasonal logistic camp; ○, sedentary village. Data in Appendix B.

[44] Among Middle Valley assemblages, evenness does not vary with NISP ($\rho = -.233$, $p = .225$), across preservation classes ($\chi^2 = 1.670$; $p = .434$) or recovery classes ($\chi^2 = 1.010$; $p = .604$). These conclusions also apply when only sedentary (NISP: $\rho = -.095$, $p = .660$; preservation: $\chi^2 = 1.520$, $p = .468$; recovery: $\chi^2 = 1.080$, $p = .299$), when only Late Woodland (NISP: $\rho = -.086$, $p = .872$; preservation: $\chi^2 = 1.238$, $p = .538$; recovery: $\chi^2 = 1.190$, $p = .275$) or when only Late Prehistoric (NISP: $\rho = -.273$, $p = .208$; preservation: $\chi^2 = .394$, $p = .824$; recovery: $\chi^2 = .633$, $p = .729$) contexts are examined.

400 – 1250 (Greenlee 2002) appears to hold true with the addition of later assemblages. When J' is compared between Late Woodland and Late Prehistoric assemblages, mean evenness does not differ ($U = 58.000$; $p = .581$), but the variance does ($F = 8.919$; $p = .006$). Late Woodland assemblages of the Middle Valley exhibit, as a group, greater variance in faunal resource exploitation than do the Late Prehistoric ones. That trend toward decreasing variation without a mean change in evenness is consistent with the notion that, prior to maize-based farming systems, a variety of ecological situations was occupied and the fauna were exploited in a variety of ways; with the establishment of maize farming systems, associated swidden techniques created similar ecological landscapes with similar faunas that could be exploited in similar ways.

Settlement context is another factor that could account for this trend. The six Late Woodland occupations are equally divided among sedentary villages and seasonal logistic camps, whereas all but two of the 23 Late Prehistoric occupations are sedentary villages. As Figure 105 shows, evenness values vary among these different settlement contexts. Three observations are of particular interest. First, evenness of assemblages from Late Woodland deposits identified as seasonal logistic camps does not differ significantly from sedentary ones ($U = 2.000$; $p = .400$). This seems to run counter to general perceptions of logistic hunting forays, that they were undertaken to acquire efficiently particular resources at particular places and times; resource exploitation geared primarily toward select resources should result in lower evenness values. Second, when assemblages from sedentary villages of the Late Woodland and Late Prehistoric periods are compared, there is no difference in the variance of evenness ($F = .077$; $p = .784$); thus, the notion that Late Prehistoric occupations were characterized by greater similarity in resource acquisition than Late Woodland ones no longer holds up. Third, there is a difference, although not quite significant at $\alpha = .05$, in mean evenness among sedentary occupations from the Late Woodland and Late Prehistoric periods ($U = 10.000$; $p = .066$). Although the sample of Late Woodland sedentary occupations is

small, it appears that evenness increased after, not during, that time period. Distinguishing whether the change occurred during or after the Late Woodland period will be critical to testing the hypothesis that resource depletion was a cause for the appearance of maize-based farming systems in the Middle Valley.

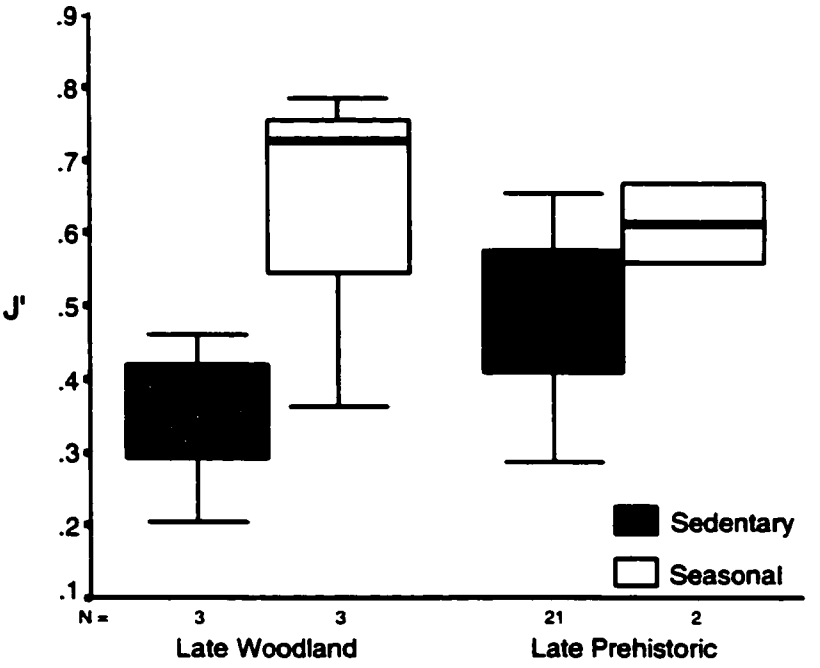


Figure 105. **Distribution of J' among middle Ohio Valley faunal assemblages with respect to settlement context and time period.**

The trajectory of resource acquisition J' from one sequence of geographically-close sedentary occupations in the Middle Valley (Pyles, Hansen, Thompson, Killen, Snag Creek, Fox Farm and Augusta) is relevant to this issue.[45] As Figure 106 shows, there is a clear increase in resource evenness through time (ρ = .955; p = .001). Although more assemblages are needed, evenness does not appear to increase between the Late Woodland and early Late Prehistoric periods. When

[45] For this group of assemblages, J' does not vary significantly across preservation class (χ^2 = 4.929; p = .177), across collection techniques (χ^2 = 2.250; p = .134), or with NISP (ρ = .607; p = .148).

increases in evenness are indicated (i.e., during the early Late Woodland and the late Late Prehistoric periods), the timing is not coincident with the establishment of maize farming.

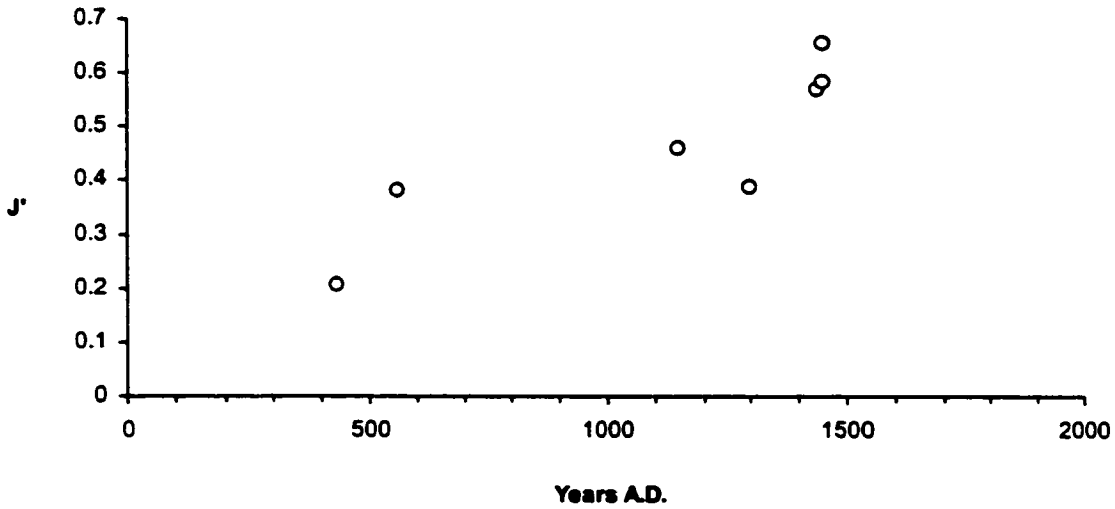


Figure 106. **Resource acquisition J' for a local sequence of Middle Valley assemblages.**

Among the Upper Valley assemblages, resource acquisition J' is significantly related to NISP (ρ = -.571; p = .021). Thus, apparent increases in J' through time in the Upper Valley (Figure 104) may be driven by variation in sample size and further consideration of the trend is not attempted here. It is worth noting, though, that there are differences between Middle and Upper Valley assemblages in the way evenness is structured.[46] Assemblages from seasonal logistic contexts of the Middle Valley are more even than those of the Upper Valley (U = 0.000; p = .036). This suggests that those populations made different uses of those kinds of

[46] Among assemblages from seasonal logistic contexts, evenness does not vary significantly with NISP (ρ = -.643, p = .086), across preservation classes (χ^2 = .528; p = .768) or recovery classes (χ^2 = 2.528; p = .283). These conclusions also apply when all sedentary contexts (NISP: ρ = -.094, p = .580; preservation: χ^2 = 3.102, p = .212; recovery: χ^2 = 1.707, p = .191), or when only Late Prehistoric sedentary contexts (NISP: ρ = -.278, p = .117; preservation: χ^2 = 1.819, p = .403; recovery: χ^2 = 1.511, p = .219), are examined.

contexts or that other processes (e.g., raptorial contributions) differed. Conversely, assemblages from sedentary villages of the Middle Valley are significantly less even than those of the Upper Valley over the entire time span (U = 81.000; p = .016), but not during the Late Prehistoric period (U = 76.000; p = .063).

An interesting aspect of the evenness of these resource acquisition classes is the close negative relationship (ρ = -.941; p < .001) between J' and the deer acquisition class (Figure 107). White-tailed deer is the dominant resource for most faunal assemblages in the Ohio Valley; frequencies of the deer acquisition class[47] are not significantly correlated with sample size (ρ = .145; p = .342). When deer acquisition frequencies are relatively low, the contributions of other resources increase proportionately. If higher evenness values are a consequence of decreased deer acquisition, this indirectly suggests there may be a decrease in the abundance of a high net-returning resource, deer, in the Middle Valley between the Late Woodland and Late Prehistoric periods. Consistent with that observation, the distribution of the deer acquisition class among sedentary contexts between the two time periods nearly differs significantly at α = .05 (U = 10.000; p = .066).

Habitat Preference Classification

The habitat preference classification is designed to track variation in the habitats exploited to acquire taxa that compose faunal assemblages. Evenness values thus reflect the relative proportion with which these habitats are represented in assemblages. When evenness is compared among assemblages with different levels of preservation (Appendix B), preservation appears to have a significant impact on assemblage evenness (χ^2 = 8.026; p = .045). Again, removing

[47] Relative frequencies of the deer acquisition class differ slightly from the relative frequency of deer bones among vertebrate genera. This is because the total number of specimens included in the two classifications differs (e.g., only specimens identified to the genus level are included in the latter total, while specimens identified to the family level may be included in the former one).

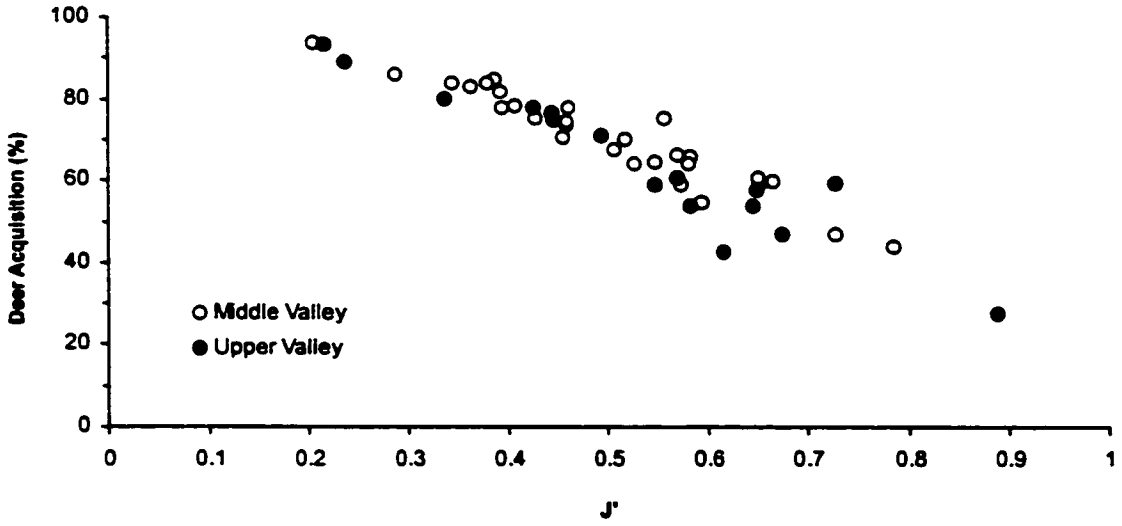


Figure 107. **Relationship between resource acquisition evenness and the deer acquisition class among assemblages from the middle and upper Ohio Valleys.** Data in Appendix B.

the five assemblages with poor preservation (Childers, Goolman, Hansen, Portman and Wylie) eliminates this relationship ($\chi^2 = 1.928$; $p = .381$) and thus they are removed from the following analysis. Evenness does not differ significantly among assemblages collected using different recovery techniques ($\chi^2 = 3.196$; $p = .202$).

Although the resource acquisition and habitat preference classifications are designed to evaluate different aspects of faunal exploitation, the resulting evenness values are positively and strongly correlated ($\rho = .856$; $p < .001$). This may be because they are tracking related changes in subsistence. Indeed, there is a strong negative correlation between habitat evenness and the abundance of secondary forest/forest edge mammals ($\rho = -.903$; $p < .001$), a class heavily dominated by deer. Although there is a strong correlation between the two classification systems, the two trajectories do vary.

For the whole dataset (Figure 108), there is a slight, albeit statistically insignificant (ρ = .258; p = .087), increase in evenness through time.[48] This is driven primarily by the Upper Valley assemblages (ρ = .462; p = .072) and not by the Middle Valley ones (ρ = .175; p = .364). Thus, in the Middle Valley, the structure of habitat exploitation remains relatively constant through time, while in the Upper Valley, there is some indication of an increase over time in the evenness with which habitats were exploited.

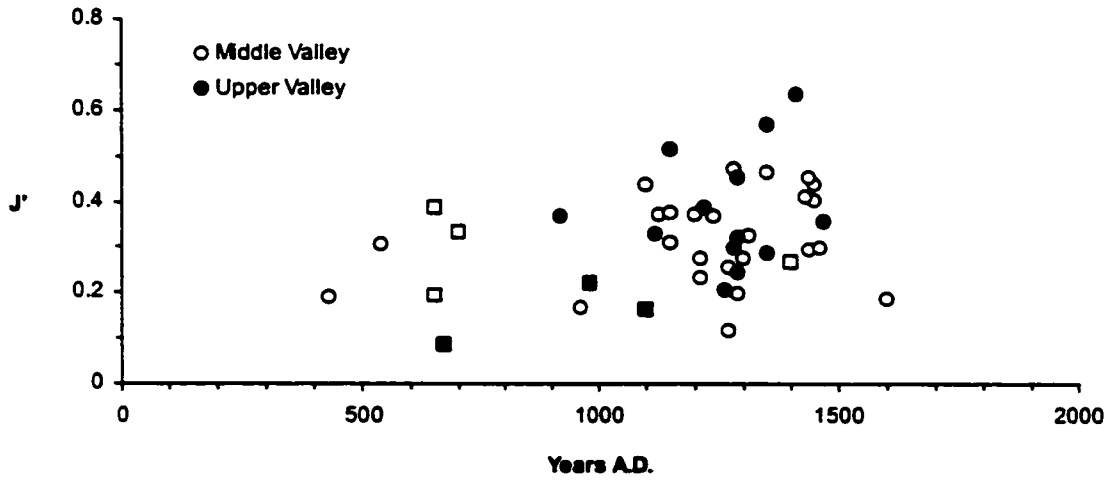


Figure 108. **Equitability index (J') as calculated using the habitat preference classification.** □, seasonal logistic camp; ○, sedentary village. Data presented in Appendix B.

Evenness calculated using the habitat preference classification is distributed among settlement contexts much as it was using the resource acquisition classification. Although evenness values tend to be lower overall for the habitat classification than for the resource acquisition classification system, the

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[48] For all assemblages, habitat preference J' does not vary with NISP (ρ = -.178; p = .241), with preservation (χ^2 = 1.928; p = .381) or with recovery (χ^2 = 3.196; p = .202). Similarly, for Middle Valley assemblages, J' does not vary with NISP (ρ = -.063; p = .747), preservation (χ^2 = 2.475; p = .290) or recovery (χ^2 = 1.582; p = .453). Among Upper Valley assemblages, J' does not vary with NISP (ρ = -.397; p = .128), preservation (χ^2 = 1.110; p = .574) or recovery (χ^2 = 1.988; p = .159).

similarity in the way they are structured is quite striking. In the Middle Valley, evenness does not differ between sedentary and seasonal logistic contexts during the Late Woodland period (U = 1.000; p = .200), nor does it differ between Late Woodland and Late Prehistoric sedentary contexts (U = 12.000; p = .101). Figure 109 plots J' for that sequence of geographically-close sedentary occupations (Pyles, Hansen, Thompson, Killen, Snag Creek, Fox Farm and Augusta) in the Middle Valley.[49] Although the evenness with which different habitats are represented appears to increase through time (ρ = .739; p = .058), it is clear that much of that increase occurs during the first part of the Late Woodland and the latter part of the Late Prehistoric periods. What happened during the critical time, the late Late Woodland period, is unknown.

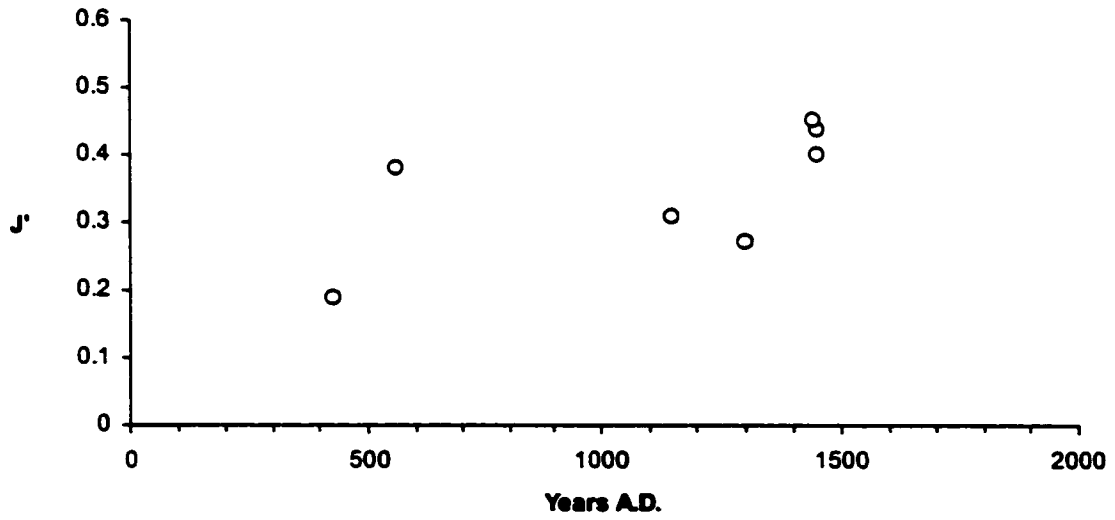


Figure 109. **Habitat preference J' for a local sequence of Middle Valley assemblages.**

Among Upper Valley assemblages, evenness calculated using the habitat preference classification (Figure 110) is greater among sedentary villages

[49] For this group of assemblages, habitat preference J' does not vary significantly across preservation class (χ^2 = 2.839; p = .417), across collection techniques (χ^2 = 2.250; p = .134), or with NISP (ρ = .321; p = .482).

than seasonal logistic camps (U = 1.000; p = .007). This is what one would expect if logistic camps were used to acquire specific resources from specific places. Accordingly, much of the apparent increase in J' through time reflects variation in Upper Valley settlement contexts. There are no differences in the evenness of habitat use between the Middle and Upper Valleys in terms of settlement context (seasonal: U = 1.000, p = .071; sedentary: U = 113.000, p = .179).

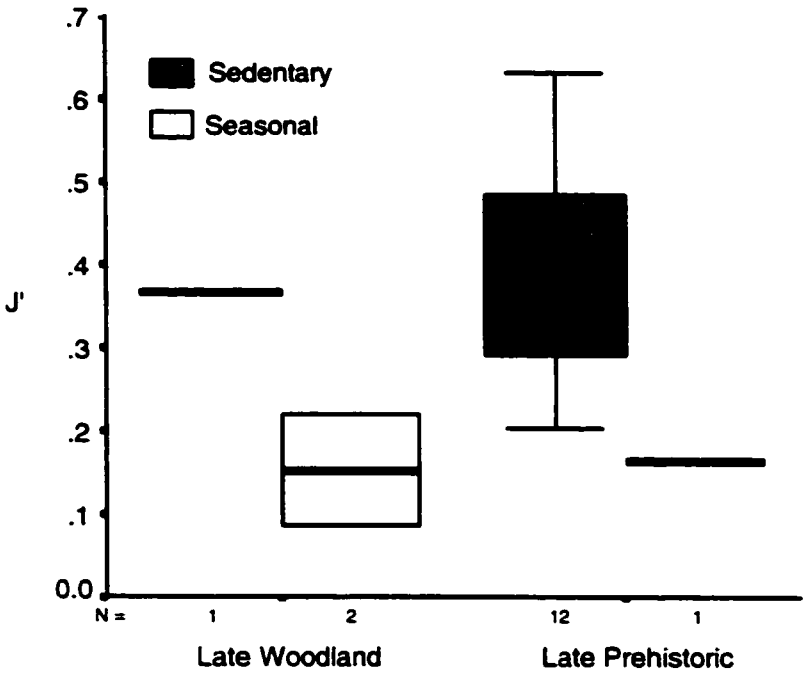


Figure 110. **Distribution of habitat preference J' among upper Ohio Valley faunal assemblages with respect to settlement context and time period.**

Summary

Faunal assemblage evenness was examined as a source of information regarding expansion of the subsistence base as a consequence of depletion of high net-returning resources. Using traditional Linnaean classes, J' was found to be strongly related to sample size. Consequently, resource acquisition and habitat preference classifications were used. In all cases, the relationship between J' and

sample size was monitored to ensure that the latter had no significant impact on evenness.

That Middle and Upper Valley assemblages exhibit different trajectories is not unexpected, given the different ecological and demographic circumstances in which those populations operated. Settlement context appears to be particularly important in accounting for the distribution of evenness values – faunal assemblages from sedentary villages and seasonal logistic camps reflect different formation processes, particularly in the Upper Valley. There is weak support for an increase in assemblage evenness (and a decrease in deer acquisition) over time, but the timing of that change (i.e., does it predate the establishment of maize farming?) is not clearly determined with the data available. A local sequence of Middle Valley assemblages indicates that increases in resource acquisition and habitat preference evenness may have occurred both long before and long after the establishment of maize farming.

PROPORTIONS OF LARGE:SMALL TAXA

Behavioral ecologists suggest that one consequence of expanding the resource base by taking more lower-ranked faunal resources is that the relative proportion of large to small body sizes will decrease. This relies on the proposition that body size is positively correlated with net yield.[50] Thus, by examining the ratio of large to small animals, researchers may be able to track the effects of resource

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[50] This position further assumes either that the primary reason faunal resources were exploited was for food or that the return rates for other raw materials (e.g., hide or fur, sinew, bone, antler) are similarly scaled with body size. Other assumptions include that exploitation technology, site function and post-depositional processes remained constant, and that there was no environmental or ecological change that would impact the abundance of animal populations (Grayson and Cannon 1999; Madsen and Schmitt 1998). Competition suppression is an additional factor that is not taken into account by this hypothesis.

depletion (Broughton 1994a, 1995; Janetski 1997). The frequencies of three mammalian taxa (squirrel [*Sciurus spp.*], rabbit [*Sylvilagus spp.*] and raccoon [*Procyon lotor*]) and one avian taxon (turkey [*Meleagris gallopavo*]) relative to artiodactyls (deer [*Odocoileus virginianus*] and elk [*Cervus canadensis*]) are examined here. A third artiodactyl, bison (*Bison bison*), is present only in unquantified archaeofaunal assemblages from Madisonville, and hence it is excluded from the index calculations. Squirrels, rabbits, raccoons and turkeys were chosen because they (1) occur in most archaeofaunal assemblages in the study area, (2) they have distinctly different body sizes and presumably net yields, and (3) they are found in habitats similar to deer and elk, so any change in the relative frequencies of those taxa should not reflect exploitation of different habitats.

Following Broughton (1995), for each of the four taxa, the relative proportion of each taxon to deer and elk was expressed as an index:

$$\Sigma \text{ Artiodactyls} / \Sigma \text{ (Artiodactyls + Other Taxon)}$$

for each assemblage. I depart from Broughton's example by referring to each of the different indices by the non-artiodactyl taxon of interest (e.g., the squirrel index, the turkey index). If the proportion of the smaller taxon to artiodactyls increases, the index becomes smaller (because artiodactyls so dominate these assemblages, the values of the indices are always relatively close to 1.0). Thus, if the exploitation of smaller taxa relative to artiodactyls increased through time, the indices should show a pattern of decreasing values with time; the slopes should be negative.

The calculated squirrel, rabbit, raccoon and turkey indices are reported in Appendix B. To avoid potential biases, seasonally-occupied logistic camps have been excluded. Because any systematic change in resource exploitation may be muddled by the inclusion of too many local sequences that may follow different trajectories (cf. Broughton 1994a; Cannon 2000), analyses presented here are restricted to local sequences. Table 8 indicates how the indices vary across different preservation and recovery classes and with NISP and age for three local

sequences with four or more faunal assemblages available from a relatively restricted geographic area: Chartiers Creek, PA (Drew, Boyle, Wylie, McKees Rocks and Portman), west-central West Virginia (Childers, Hobson, Miller and Buffalo) and northern Kentucky/southern Ohio (Pyles, Hansen, Killen, Snag Creek, Augusta and Fox Farm).

Table 8. Nonparametric Kruskal-Wallis tests evaluating the indices across preservation and recovery classes and Spearman's rank correlations with NISP and age. Statistically significant results are in boldface.

Taxon	Preservation		Recovery		NISP		Age	
	χ^2	p	χ^2	p	ρ	p	ρ	p
Chartiers Creek Assemblages:								
Squirrel	3.600	.165	0.500	.480	-.700	.188	**.900**	**.037**
Rabbit	0.400	.819	0.500	.480	.700	.188	-.100	.873
Raccoon	1.400	.497	2.000	.157	.100	.873	-.200	.747
Turkey	1.400	.497	0.000	1.000	-.300	.624	**.900**	**.037**
West-Central WV Assemblages:								
Squirrel	2.700	.259	0.600	.439	.800	.200	.200	.800
Rabbit	0.300	.861	0.600	.439	.400	.600	.600	.400
Raccoon	2.700	.259	0.000	1.000	**1.000**	**<.001**	.400	.600
Turkey	1.800	.407	2.400	.121	.400	.600	-.400	.600
Northern KY–Southern OH Assemblages:								
Squirrel	2.596	.458	1.077	.299	-.556	.195	-.673	.097
Rabbit	3.981	.264	1.077	.299	-.630	.129	**-.823**	**.023**
Raccoon	3.000	.392	1.077	.299	-.445	.317	**-.879**	**.009**
Turkey	2.839	.417	2.250	.134	.679	.094	.234	.613

Two sequences show systematic change through time in some of the indices. In the Chartiers Creek area, the squirrel and turkey indices increase, indicating greater relative exploitation of high net-return artiodactyls through time (Figure 111). Since the time span covered is after the establishment of maize

farming in the area, this sequence is not relevant to the issue of resource depletion as a force underlying that subsistence change. That artiodactyl exploitation *increased* may be a reflection of landscape/habitat alteration associated with swidden farming. Even though such a habitat change would have increased the local abundance of the lower net-return animals as well, the higher returning artiodactyls should have been exploited preferentially.

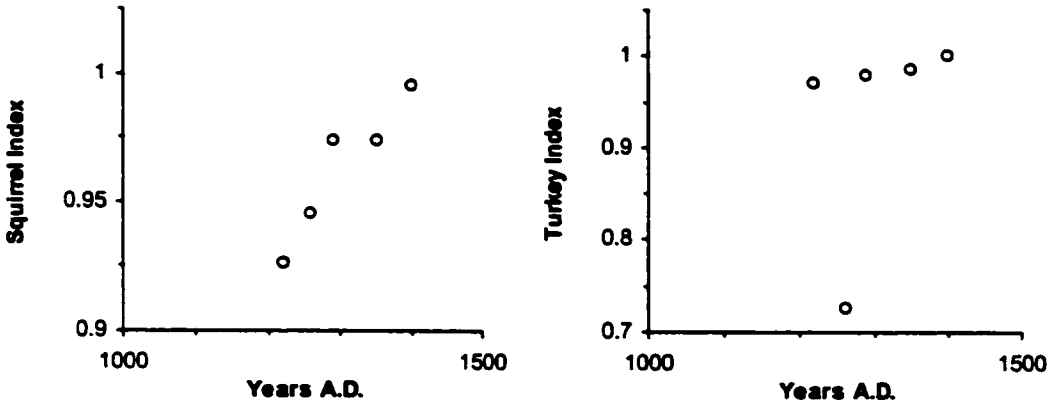


Figure 111. **Changes in squirrel and turkey indices for Chartiers Creek assemblages through time.**

Rabbit and raccoon indices from the northern Kentucky-southern Ohio sequence decrease over time (Figure 112). For the rabbit index, the decrease occurred during the late Late Prehistoric period; for the raccoon index, the timing is less clear. Although the direction of the trend is consistent with a decrease in the exploitation of high net-returning artiodactyls, the timing does not clearly support resource depletion as a cause for the appearance of maize farming. Cowan (1992) noted that, based on the density of projectile points and other tools in deposits from southwest Ohio, the exploitation of deer may have increased through time in some parts of the Ohio Valley; that trend has been attributed to trade in hides. Outside of eastern North America, others have observed similar trends among farmers toward increasing exploitation of large mammals (Speth and Scott 1989).

In his study of changes in faunal abundances in the Mimbres area, Cannon (2000) noted that an increase in the proportion of artiodactyls does not necessarily rule out the notion that resource depletion has occurred. People could have begun exploiting different territories[51] that had greater abundances of those highly-ranked taxa, for example (cf. Speth and Scott 1989). Or, it may be that landscape alteration associated with swidden farming increased the local availability of habitats preferred by artiodactyls, and thus their numbers increased in spite of heavy exploitation by people.

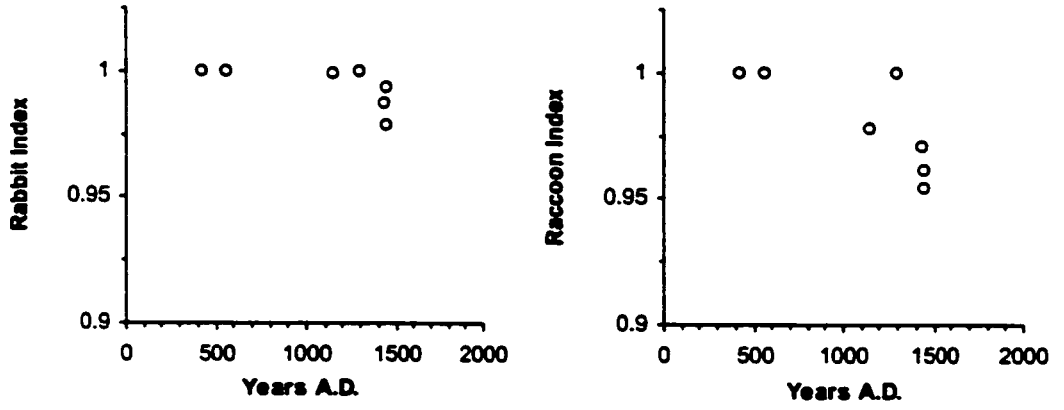


Figure 112. **Changes in rabbit and raccoon indices for northern Kentucky-southern Ohio assemblages through time.**

ANIMAL SIZE

Another consequence of heavy exploitation of fauna could be a decrease in mean body size within taxa (Broughton 1994a; Welch 1990). Limited

[51] Direct information on the location of resource acquisition could be obtained by examining the isotope and/or trace element chemistry of animal (and other) remains (Cormie and Schwarcz 1994; Durand and Shelley 1999; Ericson 1989; Kabata-Pendias and Pendias 1992; Land et al. 1980; Price et al. 1985). Variation in mtDNA of deer (and perhaps other animal) remains can be used to distinguish breeding populations (Cronin 1989; Dapson et al. 1979; Leberg et al. 1994; Travis and Keim 1995) from different ranges.

data exist on variation in body size of white-tailed deer (*Odocoileus virginianus*) as documented by astragalus length. Figure 113 plots and Table 9 lists statistical summaries of astragalus length measurements from eight Ohio Valley sites. Although there is some variation (e.g., mean astragalus length appears to decrease from northern to southern locales), the means and standard deviations of

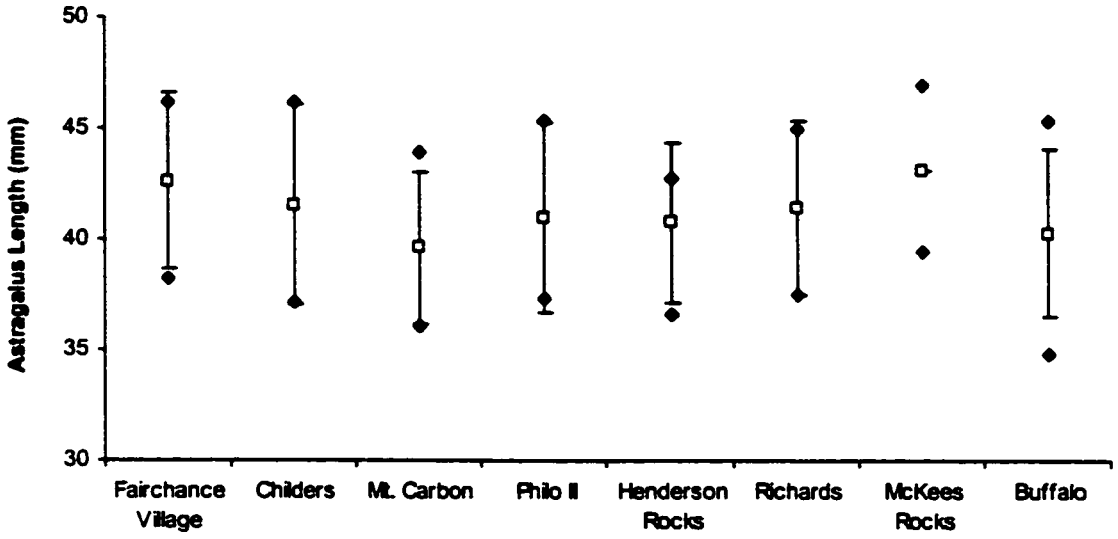


Figure 113. **Variation in white-tailed deer astragali lengths in Ohio Valley faunal assemblages.** Mean (□) ± 2 standard deviations and extreme (◆) values are plotted for eight assemblages from the middle and upper Ohio Valleys. Data are listed in Table 9. Standard deviation is not available for the McKees Rocks faunal assemblage.

astragali measurements from these assemblages do not appear to differ significantly. Note particularly the data for Fairchance Village (Middle Woodland), Childers (Late Woodland) and Henderson Rocks (Late Prehistoric). There is considerable overlap among the means and standard deviations; only the upper ends of their ranges appear to differ slightly. Since the data have been reduced to statistical summaries, there is little reason to believe that deer size truly differs among them.

Table 9. Statistical summaries of white-tailed deer astragalus length measurements for Ohio Valley assemblages shown in Figure 113. All measurements are in mm.

Assemblage (Reference)	n	Mean	2 SDs	Low Value	High Value
Fairchance Village (Hemmings 1977)	32	42.6	4.0	38.2	46.2
Childers (Oetelaar 1990)	24	41.5	4.5	37.1	46.2
Mt. Carbon (Guilday and Tanner 1965)	54	39.6	3.4	36.1	43.9
Philo II (Murphy 1977b)	67	41.0	4.3	37.3	45.4
Henderson Rocks (Tanner 1976)	20	40.8	3.6	36.6	42.8
Richards (Murphy 1977b)	81	41.4	3.9	37.5	45.0
McKees Rocks (Lang 1968)	36	43.1	--	39.5	47.0
Buffalo (Guilday 1971)	668	40.3	3.8	34.8	45.4

Individual astragalus measurements are available for the assemblages from Fairchance Village, Childers and Henderson Rocks (Figure 114). The Middle Woodland Fairchance Village distribution has the greatest proportion of large animals; not only does the Late Woodland Childers distribution have fewer large animals and more small ones, it may be bimodal; the Late Prehistoric Henderson Rocks distribution is even more biased against the larger animals and appears to be truncated. A Kruskal-Wallis test indicates that the three assemblages differ significantly ($\chi^2 = 8.927$; $p = .012$), consistent with the notion

that they may sample different populations. (One would not likely draw this conclusion based solely on the data in Figure 113, illustrating again how statistical summaries can mask the structure of the underlying data.)

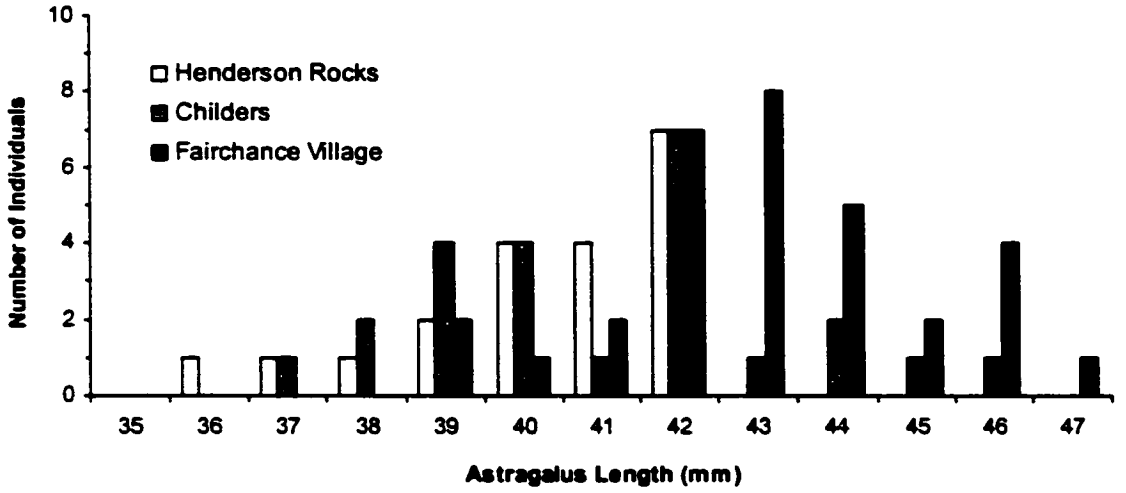


Figure 114. **Distribution of white-tailed deer astragali lengths from the Fairchance Village, Childers and Henderson Rocks assemblages.**

The data suggest a decrease in deer body size over time that could be consistent with overhunting (cf. Oetelaar 1990). Several other scenarios that could account for the apparent differences in the distribution of deer body sizes come to mind, as well. The varying distributions of astragalus length could also reflect: (1) different deer subspecies suggested to have inhabited West Virginia prehistorically (Guilday 1971), (2) variation in the quality of forage available (cf. Purdue 1991), (3) different capture technologies, (4) exploitation at different times in the life cycles of deer, (5) different sex ratios (cf. Purdue 1983), or (6) variation in the removal of astragali as a raw material source. All of these hypotheses have empirical entailments that would allow testing, but unfortunately the data to test them are not currently available.

More astragalus measurements from more archaeofaunal assemblages, establishing more firmly any temporal or geographical patterns in

deer size, would be a good first step toward resolving this problem. Next, one would need to collect data necessary to test the several hypotheses proposed to account for these different distributions (e.g., DNA to assess animal sex and the possibility of different subspecies and/or breeding populations, bone chemistry to assess climatic conditions, location of capture and/or diet, age distributions based on cementum annuli counts of associated teeth). Once those and other data are collected, that information can be integrated with comparably-detailed data on other aspects of subsistence and paleoenvironmental variation and each of the hypotheses can be evaluated.

UNDERNUTRITION

If the density of human populations in the region decreased resource availability, undernutrition could result. Identifying the specific skeletal consequences of undernutrition is, as observed earlier, not a simple task. Laboratory studies and ethnographic data from contemporary populations suggest that many skeletal pathologies and growth/developmental disruptions result from a combination of poor nutrition and infection (Goodman et al. 1991; Huss-Ashmore et al. 1982; Martorell 1980; May et al. 1993). Consequently, higher frequencies of many skeletal and dental pathologies could reflect nutritional inadequacy and/or increased disease load (the latter may be due to suppressed immunocompetence associated with poor nutrition and/or to greater population densities). Because juvenile nutrition may play a primary role in determining adult stature and the frequency of linear enamel hypoplasia (LEH), they are considered here briefly. If resource depletion was a consequence of changes in demographic structure prior to maize farming, then decreases in adult stature and increases in LEH should predate evidence for dietary change.

Stature

Variation in adult stature may reflect nutritional stress on growing subadults. The general proposition is that, when heredity and environment (e.g, altitude, temperature) are controlled, small adult statures reflect primarily disturbances during the growth process[52] due to nutritional and/or disease stress (Huss-Ashmore et al. 1982; Larsen 1997; Saunders and Hoppa 1993). Populations under chronic and severe nutritional stress do tend to have shorter statures.[53] Stature appears to be relatively insensitive to mild and short-term juvenile undernutrition, however, because even though growth may slow during times of stress, subsequent "catch-up growth" may compensate when nutrition is adequate. There is evidence that the effects of undernutrition on stature will be more pronounced in males than females; accordingly, the degree of sexual dimorphism in stature should decrease under conditions of nutritional stress (Stini 1969).

It is clear that some control is required to ensure that differences in stature are not due to heredity; populations must be related genetically. Giesen (1992) examined cranial metric and discrete traits among several Late Prehistoric populations of the middle Ohio Valley and concluded they likely shared a common heritage. Similarly, Sciulli has examined populations of the upper Ohio Valley, but the full results are not yet published; I interpret a brief discussion of his results

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[52] For archaeological applications, it is important to point out that there is a strong correlation between stunted growth and mortality. Nutritional stresses that result in stunted growth may increase the risk of death. Hence, growth-stunted juveniles are less likely to reach adulthood and will not be represented in stature estimates. Saunders and Hoppa (1993) argue the magnitude of that mortality bias is less than other sources of error involved in such analyses.

[53] The "small but healthy" hypothesis (Seckler 1980) views stunted growth as an adaptation to conditions of chronic undernutrition; the implication is that individuals of short stature have a selective advantage over non-stunted individuals in that situation. That position becomes untenable when the functional and reproductive costs of stunted growth are considered (Goodman 1994; Martorell 1989).

(Sciulli and Church 1995) as suggesting that the Late Prehistoric populations of western Pennsylvania are different from (shorter than) those further west. If this is correct and if physiological stresses were roughly similar, the statures of Middle and Upper Valley populations may not be directly comparable.

In their comparison of statures between Late Archaic, Middle Woodland and Late Prehistoric populations of the Middle Ohio Valley, Perzigian et al. (1984) found that both males and females from Late Prehistoric groups had the shortest mean statures. At the same time, though, sexual dimorphism in stature appears to be greatest for the Late Prehistoric groups. These conflicting results, one suggesting greater nutritional and/or disease stress and the other suggesting less, are difficult to reconcile. Perhaps too much error has been introduced by small samples and by the use of different regression equations to calculate the stature estimates for different samples; consequently, in the absence of additional research, those results should be viewed cautiously.

Giesen (1992) examined stature among Late Prehistoric populations of the middle Ohio Valley and northwest Ohio; her results for the Incinerator, Buffalo, Anderson and Madisonville skeletal populations are of particular interest here. She found similar patterns of long bone growth between samples from Incinerator and Buffalo, both evidencing slightly slower growth than among modern Euroamericans, suggesting a more stressful environment. There is some evidence for a general reduction in stature over time, with males showing greater variation in stature than females with time in the Late Prehistoric period. Individuals from Madisonville were especially small, but other indicators of environmental stress do not support an interpretation of severe nutritional or disease stress. Interestingly, average statures of Late Prehistoric populations in western Pennsylvania (Sciulli and Church 1995) are also much shorter than most groups of the Middle Valley and they are comparable to those from Madisonville in southwest Ohio.

Figure 115 shows the available stature data for populations in the Ohio Valley. Stature estimates for the Saddle, Continental Construction and Pinnacle locales were used as published because the values were derived using the formulae of Sciulli et al. (1990). To ensure comparability, I used femoral and/or tibial lengths reported for other skeletal assemblages to recalculate statures according to the same set of formulae. There are apparent trends of decreasing stature with time through the Late Woodland and Late Prehistoric periods for both sexes, but neither is statistically significant at $\alpha = .05$ (females: $r = -.410$, $p = .274$; males: $r = -.181$, $p = .536$). Incidentally, male and female statures are significantly correlated ($r = .954$; $p = .012$), indicating that however stature may have varied for these populations, it did so similarly for both sexes.

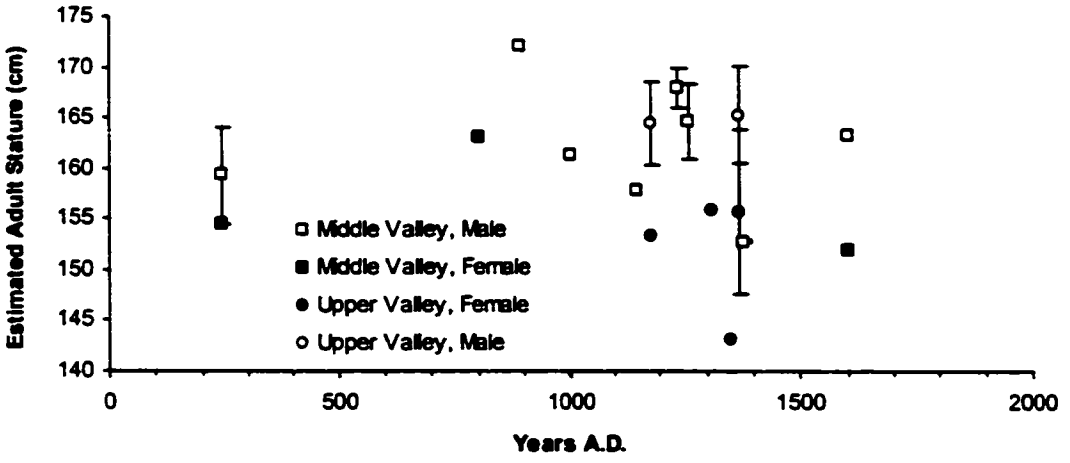


Figure 115. **Adult stature estimates for Ohio Valley groups.** All estimates are calculated using the formulae of Sciulli et al. (1990); calculations done for this research do not include age corrections. Error bars indicate one SD. Data are presented in Appendix B.

Linear Enamel Hypoplasia

A linear enamel hypoplasia (LEH) appears as a band of thinner enamel that results when processes of enamel formation are disturbed (Goodman et al. 1984; Huss-Ashmore et al. 1982; Larsen 1997). In modern populations, LEHs occur when the individual is under nutritional stress, due to problems with food

quantity, quality or absorption (the latter being disease-related). As a permanent record of stress, the timing of these developmental defects can be determined by measuring their positions on the teeth in which they occur. Hypoplasias on deciduous teeth reflect conditions beginning roughly 5 months prior to birth through the first year, while those on permanent teeth reflect the first seven years of life.

Perzigian et al. (1984) found higher frequencies of moderate/severe LEH among permanent teeth from the Late Prehistoric population at Turpin than in Late Archaic and Middle Woodland populations from the Ohio Valley. Apparently Perzigian et al. did not recognize sample size as a potential problem; Figure 116 shows that there is a significant correlation between the number of teeth examined and the frequency of moderate and severe LEH ($r = .906$; $p < .001$). Analyses by others corroborate their results, however, suggesting that the sample size correlation is coincidental. For example, Cassidy (1984) compared frequencies of LEH between comparable numbers of (Late Archaic) Indian Knoll and (Late Prehistoric) Hardin Village populations. Although she found no significant difference in the overall incidence of LEH, most Indian Knoll LEH cases were mild; teeth from Hardin Village had significantly more cases of severe LEH. In addition, while no deciduous teeth from Indian Knoll displayed LEH, roughly 9% of deciduous incisors and 12% of deciduous canines/molars from Hardin did.

Sciulli (1977, 1978) compared deciduous and permanent dentition between pre-Late Woodland (Glacial Kame, Adena and Hopewell) and post-Late Woodland populations in the Ohio Valley. Among deciduous teeth, Sciulli (1977) found significantly greater frequencies of severe LEH associated with prenatal development in the later group (Figure 117); differences were not significant among the other age groups. The permanent teeth also show significantly greater frequencies of severe LEH among post-Late Woodland populations (Sciulli 1978). He notes that the lower frequency of LEH among pre-Late Woodland populations may reflect, in part, the possible "high status" (presumably associated with reduced

exposure to environmental stress) of individuals recovered from elaborate burial contexts that constitute that sample.

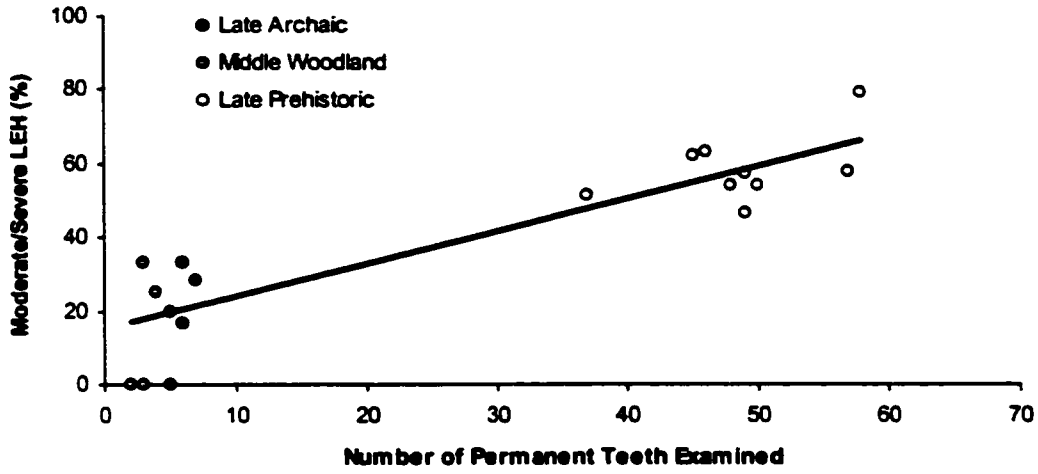


Figure 116. **Number of permanent teeth and frequency of moderate and severe linear enamel hypoplasias.** Data from Perzigian et al. (1984).

Summary

The osteological paradox (Wood et al. 1992) notwithstanding, these and other skeletal pathological data (e.g., porotic hyperostosis, periosteal lesions) consistently point to a significantly higher frequency of nutritional- and/or disease-related stress among maize farmers of the Late Prehistoric period than among populations from earlier time periods. It is not, however, possible to establish when or how skeletal pathologies increased. Although some data have been collected which might be useful, they are not published in an appropriate format for that purpose. Most efforts are temporally insensitive, lumping the relevant observations by time period. More critically, published data on Late Woodland populations are lacking (cf. Sciulli 1998). Consequently, this analysis sheds little light on the potential role of undernutrition in accounting for subsistence change.

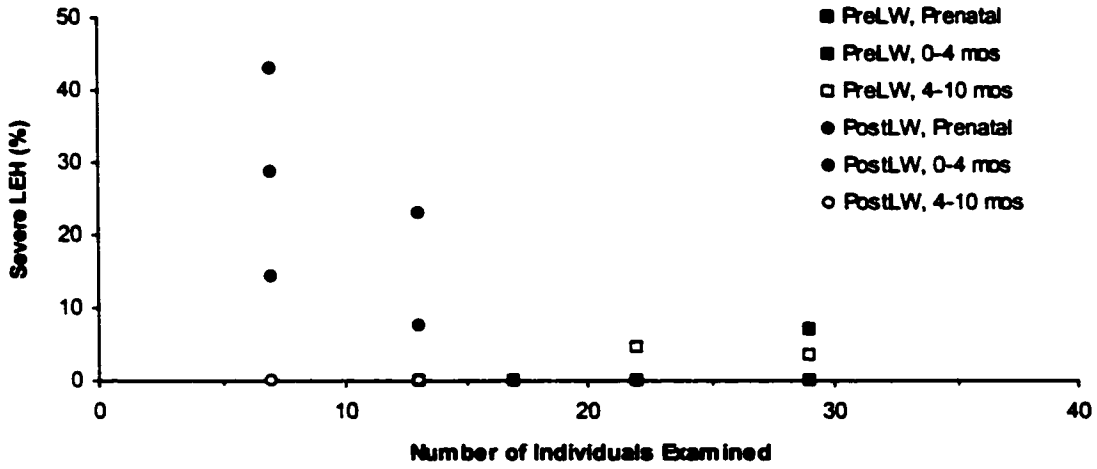


Figure 117. **Number of individuals with deciduous dentition and the frequency of severe LEH during different developmental ages between pre-Late Woodland and post-Late Woodland populations.** Multiple (identical) symbols represent different teeth. Data from Sciulli (1977).

THE CASE FOR DECREASED RESOURCE AVAILABILITY

I have considered several lines of evidence bearing on the argument that subsistence change was caused by reduced resource availability due to overexploitation by an increasing human population. It is unfortunate that the time of critical interest, the latter half of the Late Woodland period, is generally poorly-represented; in most cases, grouped data must be compared and it is not possible to establish when changes occurred. Counter to expectations of the resource depletion hypothesis (but consistent with the notion that maize farming systems were more specialized than the ones that preceded them), botanical richness was lower among Late Prehistoric assemblages than among Late Woodland ones. There were limited cases in which the evenness of faunal resource exploitation increased through time, but the timing of those changes does not appear to meet expectations of the resource depletion hypothesis.

Many of the faunal assemblages are dominated by deer and even after maize farming systems were established, faunal exploitation continued to

emphasize artiodactyls. There is weak evidence for a decrease in the abundance of high net-returning artiodactyls relative to smaller, presumably lower net-returning taxa through time, but the timing of that change does not clearly support resource depletion as a cause for maize farming. In addition, there is evidence for an increase in the abundance of artiodactyls relative to lower net-returning taxa, but the timing of that increase clearly post-dates maize farming. Although mean body size for deer *may* have decreased over time, overpredation is not the only potential cause; data necessary to evaluate other potential factors are not available.

Bioarchaeological data indicate generally that Late Prehistoric populations may have been under greater nutritional and/or disease stress than in earlier time periods; critical data on Late Woodland groups are unavailable and thus, the timing and nature of the increase in undernutrition are not known. An important point to bear in mind is that, even though individual "health" may have deteriorated during the Late Prehistoric period, reproductive fitness (as evidenced by larger populations) must have increased. Such is not unexpected given the major change in diet that has been documented.

COMPETITION

Differential success in competition for resources is one possible cause for subsistence variation and, in Chapter Three, two different sorts were described: competition among human groups and interspecific competition. Both sorts of competition may result in increased costs of acquiring resources, and they may both be influenced by changes in the local demographic structures of the parties involved.

COMPETITION AMONG HUMAN GROUPS

Evidence of competition among human groups is best seen in defensive, i.e., access restricting, elements of settlement location and architecture. Defensive classes were constructed using variables of settlement location and the

presence of defensive structures. One class, Probably Not Defensive, includes settlements located on bottomlands that lack evidence of defensive structures (where excavations were clearly adequate to have encountered such structures if present). A second class, Probably Defensive, includes settlements that have clear evidence for defensive constructions (palisades, bastions, etc.). Other classes are Possibly Defensive (all settlements in upland situations, settlements that were at least partially enclosed by a ditch [but lacking evidence for other defensive constructions], and settlements that "possibly" had palisades), Unknown (settlements for which insufficient data are available) and Not Relevant (logistic camps).

Previous research has indicated increased frequencies through time in the incidence of settlements with defensive structures. In Figure 118, I show the temporal distribution of the two most certain classes in this sample. When the distribution of these two classes is examined for Middle and Upper Valley settlements separately, very different pictures emerge. Probably Defensive contexts

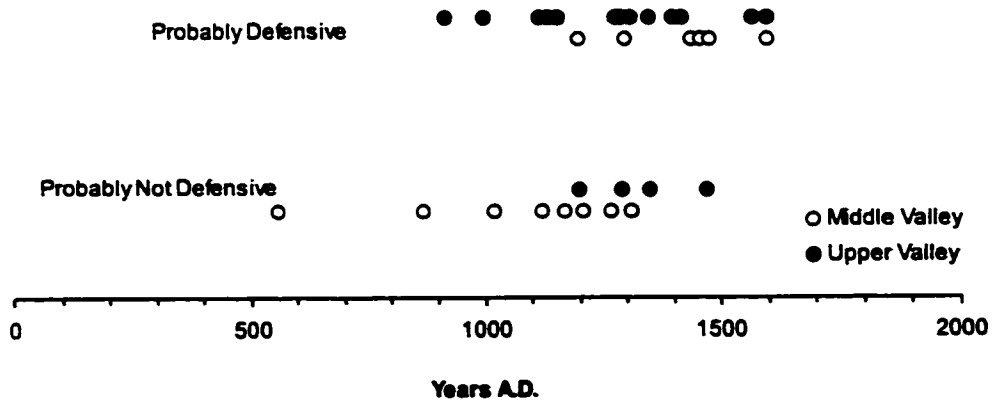


Figure 118. **Temporal distribution of the two most certain defensive classes among settlements of the Middle and Upper Valleys.** Data are presented in Appendix B.

occur late in the Middle Valley sequence and they appear to replace Probably Not Defensive ones; the age distributions of the two classes differ signficantly (U = 5.000; p = .003). In the Upper Valley sequence, Probably Defensive contexts occur quite early in the sequence and the sample includes only a few, relatively late, Probably Not Defensive ones; the age distributions do not differ (U = 28.000; p = .750).

More important, though, is how subsistence may have varied across the different defensive options. Figure 119 shows the structure of isotopic diets across the two most certain defensive classes (Probably Defensive and Probably Not

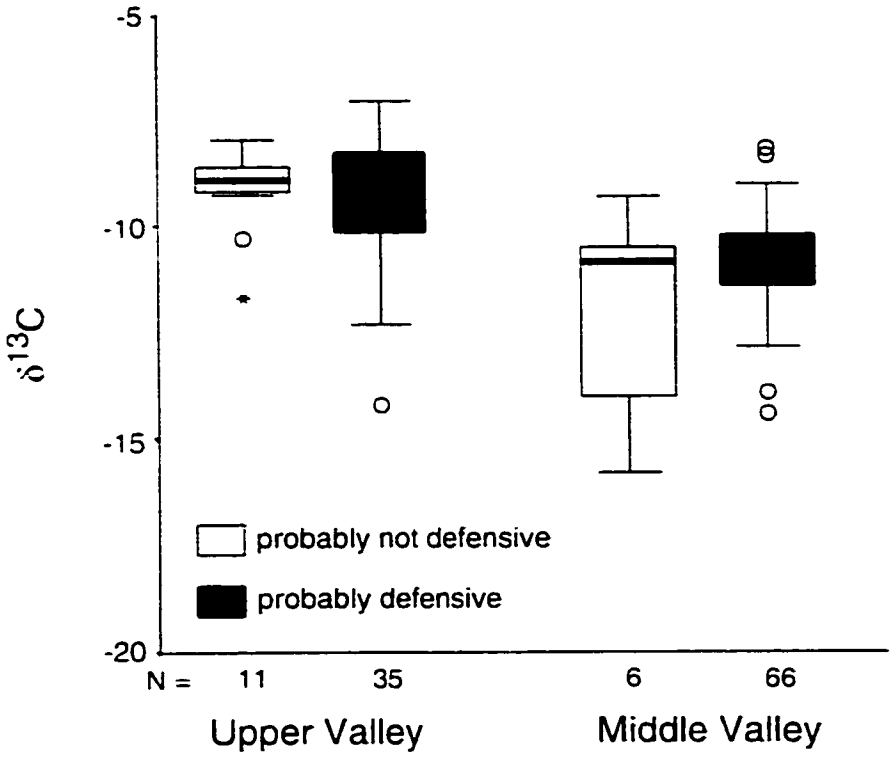


Figure 119. **Structure of isotopic diet across different defensive classes among Upper and Middle Valley populations.** The Os indicate outliers (> 1.5 box lengths); the * indicates an extreme outlier (> 3 box lengths).

Defensive) for Late Prehistoric (A.D. 1000 - 1650) populations of the Upper and Middle Valleys. Among the Upper Valley populations, which are generally believed to have been most strongly influenced by intergroup competition, there is no significant difference in mean $\delta^{13}C$ values between the two classes ($t = 0.576$; $p = .568$). Among the Middle Valley populations, mean $\delta^{13}C$ values do not differ significantly between those two classes, either ($t = -1.043$; $p = .343$).

Given that local physiography appears to have been an important factor in determining isotopic diet and the potential role it may play in defense, it might be prudent to examine isotopic diet across both parameters. Figure 120 shows how, for Upper Valley populations, isotopic diet is more enriched for individuals in upland than bottomland settings in Probably Defensive situations ($t = 3.483$; $p < .001$); this is consistent with previous observations about the effect of local physiography on isotopic diet. For individuals in upland settings, those living in Probably Defensive situations are more enriched than those in Possibly Defensive situations ($t = -2.659$; $p = .006$). To the degree that the two defensive classes actually reflect differences in intergroup competition, this result makes sense. Kruskal-Wallis tests indicate maize consumption increases significantly through time for upland individuals in probably defensive situations ($\chi^2 = 9.404$; $p = .005$), but not for those in possibly defensive situations ($\chi^2 = 1.868$; $p = .197$).

In Figure 120, the isotopic diets of individuals in broad bottom settings in Probably Not Defensive and Probably Defensive situations appear to differ in a direction that would be counter to the intergroup competition argument; the differences are not significant at $\alpha = .05$ ($t = 2.032$; $p = .056$). All eight individuals in the broad bottom Probably Not Defensive sample came from a single locale, Bunola; that $\delta^{13}C$ values are less variable than in the broad bottom Probably Defensive sample is understandable. More relevant to this question, though, is the composition of the Probably Defensive sample. There is considerable variation in the form of defensive structures, ranging from simple palisades to palisades with

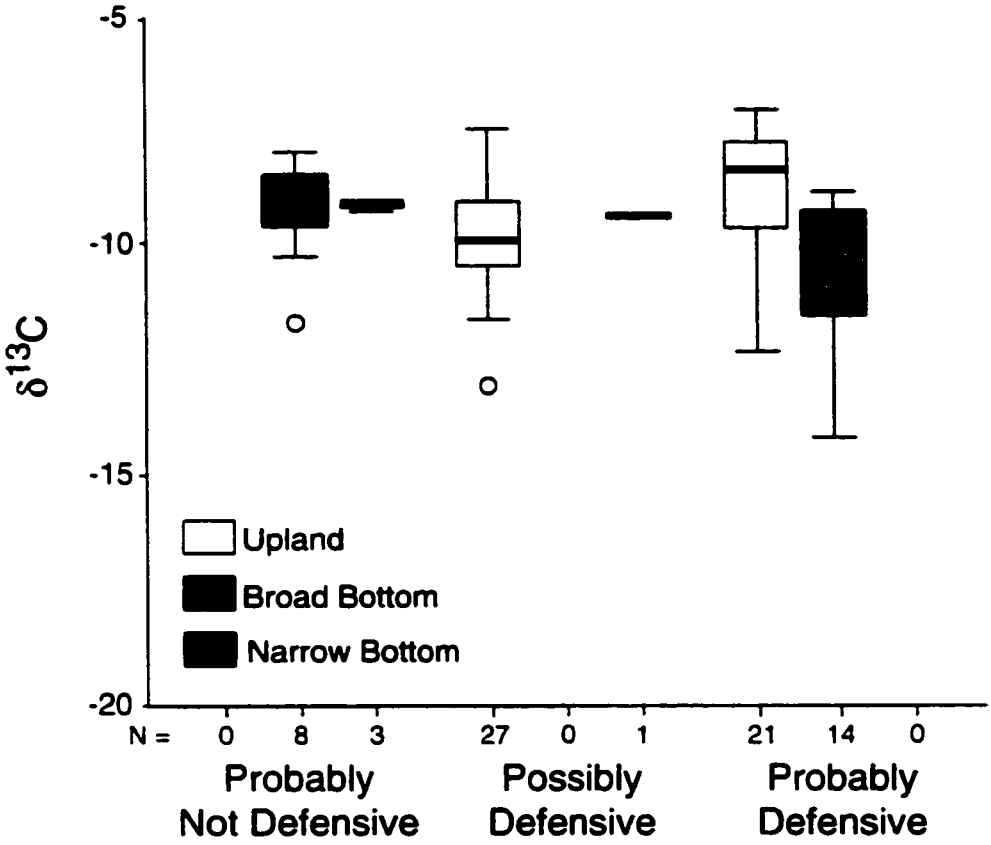


Figure 120. **Structure of $\delta^{13}C$ values for Upper Valley individuals in upland and bottom physiographic settings across defensive classes.** The Os indicate outliers (> 1.5 box lengths).

bastions, overlapping entry gates, ditches or even double palisades. There are four Upper Valley settlements with isotopic data for which one or more of the latter, more extreme, defensive attributes have been reported: Bonnie Brook, McKees Rocks, Johnston and Sony. As Chapter Two notes, individuals living at the first three of those locales (which also happen to be in broad bottom settings) have been identified as probably intrusive into the Monongahela culture area from elsewhere (Buker 1968; George 1995, 1997; Johnson 1998); the fourth site, Sony, is in an upland setting and it is not relevant here. Interestingly, as a group, the isotopic diets of individuals from these three places are significantly depleted when

compared to diets of individuals from other broad bottom, Probably Defensive contexts ($t = 2.546$; $p = .013$). Either these individuals maintained more depleted isotopic diets in the face of intergroup competition or they had not equilibrated from their original and presumably lower-maize diets. If the latter scenario is correct, then including individuals from Johnston, Bonnie Brook and McKees Rocks would not be appropriate; their removal from this analysis eliminates the dietary difference between the two defensive classes in broad bottom settings ($t = 0.523$; $p = .611$).

Among populations of the Middle Valley, the isotopic diets of individuals living under situations that are probably defensive also appear to vary according to local physiography. In Figure 121, Probably Defensive groups situated in narrow bottom settings are more enriched than those in broad bottom settings ($t = 6.559$; $p < .001$). The isotopic diets of individuals occupying broad bottom settings do not vary significantly with regard to the Probably Not Defensive and Probably Defensive classes ($t = -0.529$; $p = .618$). Thus, variation in isotopic diet among individuals in different defensive situations of the Middle Valley is more likely due to physiography than differences in the level of intergroup competition.

Trauma

Intraspecific competition, though not necessarily intergroup competition, would result in an increased number of traumatic injuries inflicted by weapons. Previous efforts to study trauma associated with intergroup fighting (e.g., Larsen 1997; Milner 1995; Milner et al. 1991) have identified several relevant variables observable in archaeological burial assemblages: projectile points lodged in bones, cranial and upper body fractures, mutilations (cranial cutmarks consistent with scalping, dismemberment). Although there is evidence for intergroup conflict in the prehistory of eastern North America as early as the Early Archaic period, it seems to be especially prevalent among assemblages from the Late Prehistoric period (Larsen 1997; Milner 1995).

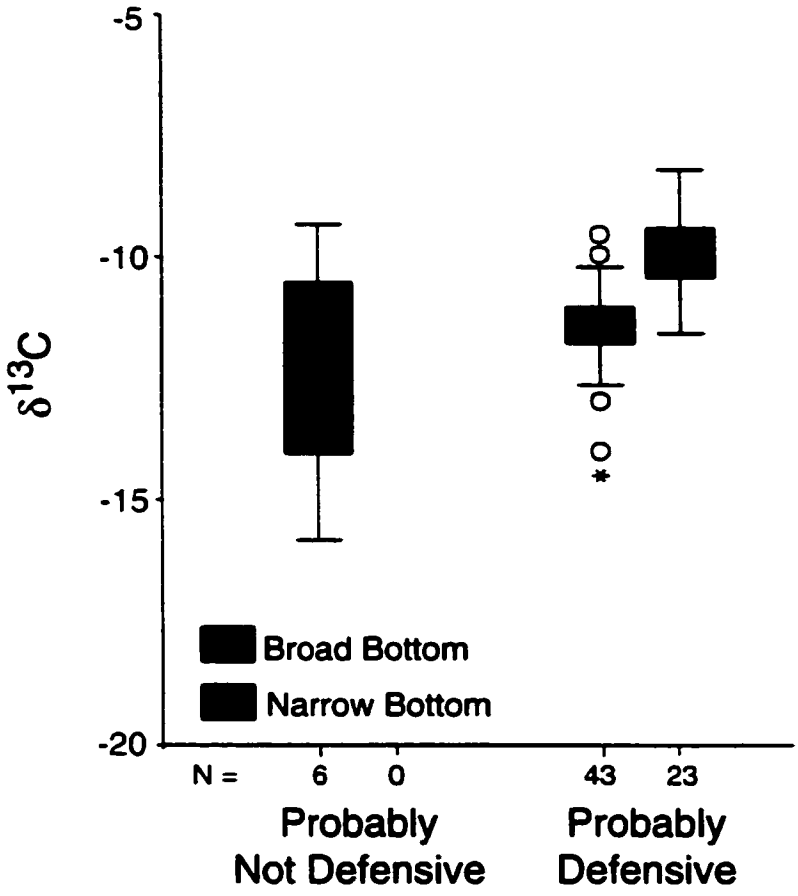


Figure 121. **Structure of $\delta^{13}C$ values for Middle Valley individuals in broad and narrow bottom physiographic settings across defensive classes.** The Os indicate outliers (> 1.5 box lengths); the * indicates an extreme outlier (> 3 box lengths).

Relevant observations about human skeletal assemblages from the locales examined here tend to be unevenly reported, severely limiting the quantity and quality of data regarding trauma, both lethal and nonlethal. In most cases, if no evidence of trauma was reported, it could not be assumed that none were present. Rarely were osteological analyses reported in sufficient detail that the absence of trauma could be considered a significant observation. Accordingly, the frequency of traumatic injuries for most assemblages is best considered a minimum estimate. Although better data are clearly needed in order to examine this aspect of

intergroup competition systematically, I have attempted to compile all of the available data. Figure 122 plots the frequency of trauma in Middle and Upper Valley assemblages through time. Interestingly, the locales with relatively high frequencies of trauma are found in the Middle Valley even though intergroup competition appears to have been more important in the Upper Valley.

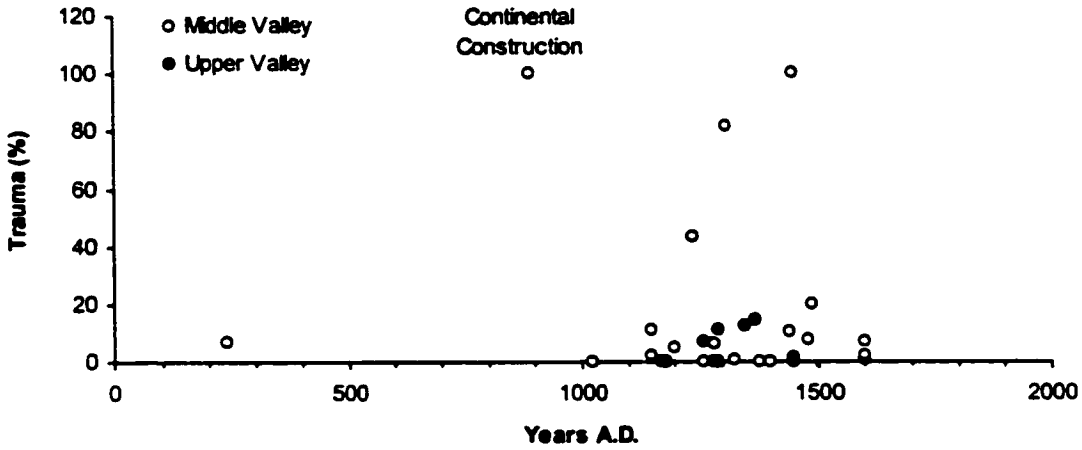


Figure 122. **Frequency of traumatic injuries in Ohio Valley human skeletal assemblages through time.** Data are presented in Appendix B.

There is no evidence for systematic change in traumatic injury across time periods ($\chi^2 = 0.646$; $p = .421$) in the Upper Valley. When the single Late Woodland individual from the Continental Construction site is excluded, there is no change among Middle Valley groups either ($\chi^2 = 2.845$; $p = .241$). Since the incidence of trauma was anticipated to vary with intergroup competition under the competition hypothesis, the frequency of trauma should vary across different defensive classes. In the Upper Valley, trauma does not vary significantly ($t = 0.028$, $p = .979$) across Possibly Defensive and Probably Defensive classes (no trauma data are available for the Probably Not Defensive class), but the sample is quite limited. In the Middle Valley, the frequency of trauma among the Probably Not Defensive and the Probably Defensive classes does not differ ($t = 0.881$; $p = .540$). Thus, the frequency of traumatic injury apparently provides different

information about competition than do the variables that comprise the defensive classes.

Following the logic espoused earlier regarding the relationship between intergroup competition and subsistence, we might expect isotopic diet to vary with the frequency of trauma. Figure 123 plots the mean stable carbon isotope ratios for Upper and Middle Valley groups against the frequency of trauma. Among Upper Valley groups, there is no significant correlation between isotopic diet and frequency of trauma (ρ = -.516; p = .295), nor does the mean isotopic ratio differ between groups with and without trauma (t = 1.563; p = .193). The situation is different in the Middle Valley. Mean isotopic diet in Middle Valley groups is positively correlated with trauma (ρ = .848; p < .001); discounting the groups with no evidence of trauma, a positive correlation is still evident between maize consumption and trauma (ρ = .750; p = .052). Middle Valley groups that lack evidence of trauma have significantly lower mean isotope ratios than those with

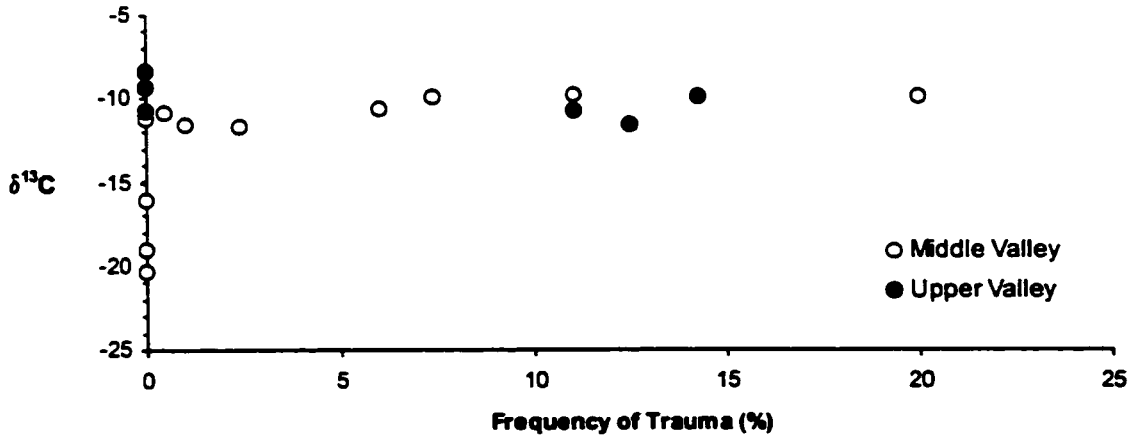


Figure 123. **Mean isotopic diet versus the frequency of trauma for Middle and Upper Valley groups dated post-A.D. 900.**

evidence of trauma (t = -3.888; p = .008). Groups experiencing greater intercommunity competition, as reflected in the incidence of traumatic injuries, apparently had a greater dietary commitment to maize. Those populations with

isotope data and that lacked traumatic injuries tend to be located in southwest Ohio, where isotope ratios tend to be lower.

INTERSPECIFIC COMPETITION

Agroecologies are beneficial to a variety of animals, some of which compete with people for the cultivated plants. Effort may be required to suppress competition for garden products from some animals. Indeed, this is one component of garden hunting[54] scenarios (Conklin 1957; Linares 1976; Neusius 1996). That some faunal remains owe their presence in archaeological deposits to competition is likely. Thus, competition with other organisms for resources may introduce variation into the subsistence record. Assessing the degree to which competition suppression is responsible for aspects of the archaeofaunal record is a difficult task, relying on evidence for (1) increased frequencies of known potential competitors (e.g., deer, raccoons, rabbits, bears, squirrels, woodchucks, opossums and/or turkeys), (2) local acquisition, and/or (3) differential use (e.g., cutmarks, burning, degree of articulation) of the body. Only the first variable will be considered here because sufficient data to evaluate the others are not available.

Among individual taxa, turkey (*Meleagris gallopavo*) and opossum (*Didelphis marsupialis*) both show systematic change with time. As Figure 124

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[54] In the Eastern Woodlands and elsewhere, garden hunting scenarios rely on the observation that many of the animal taxa exploited by Late Prehistoric populations prefer disturbed ecologies like those created by swidden farming. Thus, land clearance and shifting cultivation of maize and other crops created a mosaic of microenvironments well-suited for these taxa, increasing their local population densities. Their exploitation was not only economically attractive, but it also may have been necessary to suppress competition for crops. There is some disagreement in the literature how gardens might affect the relative abundance of large mammals (Speth and Scott 1989).

shows, the relative frequencies of both taxa[55] increased at roughly A.D. 1100. The timing of this change corresponds to the timing of demographic change among Ohio Valley populations as indicated by roofed area and settlement size. That these taxa

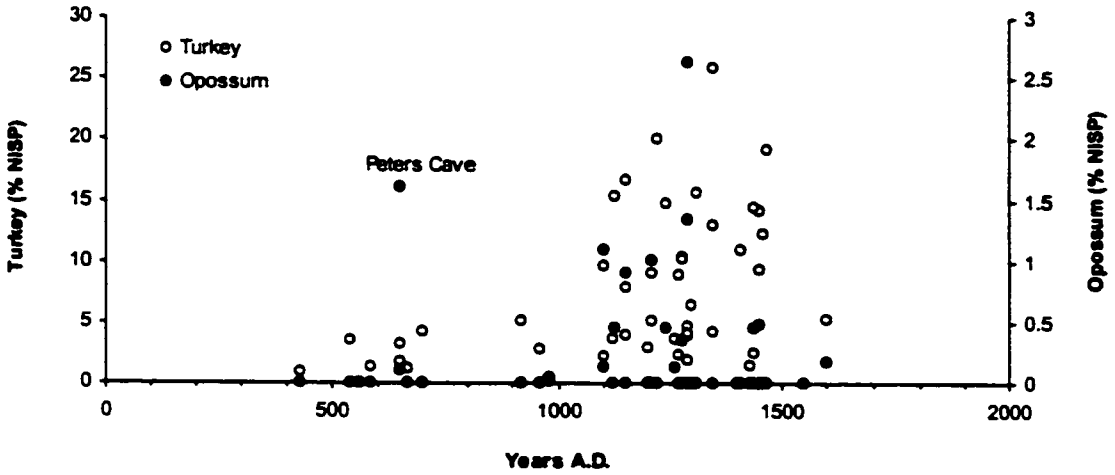


Figure 124. **Relative frequencies of opossum and turkey in Ohio Valley faunal assemblages.** Data are presented in Appendix B.

became a more significant component of the subsistence system at that time could be due to the depletion of other resources with greater net return rates. Recall, however, that the Turkey Index did not indicate increased exploitation of turkey relative to deer such as would be expected if resource overexploitation were at play. Accordingly, increased abundances of turkey and opossum are unlikely to be a result of the depletion of higher net-returning taxa.

Perhaps these taxa were increasingly a threat to plant resources and thus, some measure of competition suppression was at play. With respect to the opossum, Neumann (1984) has suggested that opossums were competing for the persimmon crop; persimmons have not been shown to have been an important

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[55] The relatively high frequency of opossum remains in the Late Woodland Peters Cave assemblage is likely a function of the very small sample size there (opossum = 1 bone of 73 NISP).

component of Late Prehistoric diet in the Ohio Valley. Opossums are, however, known to eat maize, as are turkeys. Some turkeys have isotopically enriched bone chemistries (Table 4), indicating they consumed a C_4 resource, presumably maize. No opossum remains have been similarly analyzed. Although Conard (1988) and Shane (1988) have suggested the enriched turkeys may have been "kept" in villages, it is also possible they were raiding the maize crop. More data on the demographic structures of both of these prey populations, their isotopic diets, and in the turkey case, a comparison of musculature and/or bone histology between wild and purportedly "kept" individuals, may allow further evaluation of these scenarios.

It is also possible that the increased abundances of these taxa in faunal assemblages simply reflect increases in the local population density of these animals brought about by habitat alteration. These animals prefer the sort of disturbed, forest edge habitats that would be created by swidden systems. Accordingly, as the proportion of those habitats increased, so might the relative abundance of those kinds of animals. An increase in the availability of easily captured, relatively high net-returning resources would be reflected accordingly in the composition of faunal assemblages.

SUMMARY

To the degree that competition between human groups is reflected in the defensive classes constructed here, there is some support for the notion that intergroup competition impacted prehistoric subsistence. In the Upper Valley, groups living in defensive situations in upland settings exhibit greater dietary commitment to maize than upland groups living in less certain defensive situations. Maize consumption did not vary with respect to defensive situation for Upper Valley groups living in bottomland settings, nor did it differ among groups of the Middle Valley. The incidence of traumatic injuries, presumably (but not necessarily) associated with intergroup competition, does not correspond to defensive situation, nor does it vary through time; a more detailed consideration of trauma is hampered

by a small sample and uneven reporting. Isotopic diet does not appear to vary with the frequency of traumatic injury among Upper Valley groups, but it does among Middle Valley groups, although this may be fortuitous.

Competition was likely not restricted to other human groups. Increases in the frequency of turkey and opossum remains are consistent with the notion that people were protecting resources, in particular the maize crop, from those predators. Competition suppression is not the only hypothesis by which to account for those changes, however. For example, ecological changes which increased the amount of those animals' preferred habitats may have allowed greater population densities; their increased frequencies in archaeofaunal assemblages may reflect their greater availability in the surrounding catchment. Other data which consider animal diet, the use of the body, locality and season of acquisition, and demographic structure of the prey populations will be needed to further assess the role of competition suppression.

INTRA- AND INTER-GROUP COOPERATION

Another set of hypotheses has suggested that intra- and inter-group cooperation may have impacted prehistoric subsistence systems. Although it is not possible with the data in hand to demonstrate food-sharing, the case can be made that those individuals who cooperated in other activities might be more likely to cooperate with respect to food acquisition and consumption. In Chapter Three, variables were suggested that might provide evidence for intra- and inter-group cooperation. Large construction projects (e.g., earthworks and palisades) as a reflection of intra-group cooperation and the presence of foreigners as an indicator of inter-group cooperation are examined below.

INTRA-GROUP COOPERATION: MOUND AND PALISADE CONSTRUCTION

The construction of features like earthen mounds or palisades provides perhaps the best evidence for intra-group cooperation. *If* intra-group cooperation associated with mound or palisade construction is correlated with cooperation in food-sharing, and *if* food-sharing included agricultural crops, then isotopic analysis may be useful. In particular, *if* intra-group cooperation acted to decrease dietary variation among individuals, then those groups with mounds or palisades might have lower variances with respect to isotopic diet. In my sample, no mounds were reported for any of the Late Prehistoric locales in the Upper Valley (they were no longer being constructed); in the Middle Valley, there is no difference in $\delta^{13}C$ variance ($t = -1.143$; $p = .267$) between locales ($\geq$ 900 A.D.) with and without mounds. When $\delta^{13}C$ variance is compared between Upper Valley locales ($\geq$ 900 A.D.) with and without palisades, there is no difference ($t = 1.147$; $p = .174$). In the Middle Valley, there is a difference in $\delta^{13}C$ variance among locales ($\geq$ 900 A.D.) with and without palisades ($t = 10.763$; $p < .001$), but the sample of locales clearly lacking palisades is small ($\delta^{13}C$ variance is available for only one, Roseberry Farm) and they are temporally earlier than locales with palisades. More importantly, though, the variance for Roseberry Farm is high due to the inclusion of a "foreigner" (see below). When that individual is removed from the sample, $\delta^{13}C$ variance decreases and the difference between locales with and without palisades is no longer significant ($t = 0.162$; $p = .878$). No difference in isotopic dietary variance that might result from intra-group cooperation is detected.

INTER-GROUP COOPERATION: FOREIGNERS

As pointed out earlier, the presence of "foreigners" (i.e., people not raised with the burial population) is generally considered to indicate cooperation

among groups.[56] In this region, heritable and nonheritable (e.g., cranial deformation, ear exostoses) skeletal variants, unusual burial treatment and unusual ceramic attributes are commonly-used archaeological indicators for the presence of foreigners. Of seven locales with skeletal assemblages believed to contain such individuals (Mt. Carbon, Richards, Buffalo, McJunkin, Johnston, Roseberry Farm and Duvall), isotopic data from more than one individual are available for three locales.

At Roseberry Farm, of the individuals analyzed isotopically, one was identified as a "foreigner" on the basis of his unusual burial treatment (Graybill, p.c.). That adult male was recovered from a pithouse rather than the burial mound where most adults were interred. An isotopic outlier (Figure 125), he apparently consumed significantly less maize than others in the group ($t = 4.073$; $p = .014$). At two other locales, Duvall and Johnston, foreigners are believed to make up part of the burial population, but it is not clear whether any of the specific individuals analyzed isotopically are foreigners (i.e., burial/feature numbers of "foreigners" don't correspond with sample numbers of isotopically-analyzed individuals). The isotope data from these locales (Figure 125) suggest that one analyzed individual from each locale ate a different isotopic diet; these individuals may have grown up elsewhere, consuming different diets. Since the source of foreigners is mostly unknown, their presence is admittedly weak evidence for inter-group cooperation; indeed, it may be evidence of competition. Demonstrating that individual translocation was accompanied by the exchange of subsistence resources would also require detailed analyses of DNA, trace elements and/or stable isotopes of remains.

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[56] This is in spite of ethnohistoric documentation elsewhere in the East that foreigners might be better regarded as evidence of competition than cooperation (e.g., Brandão 1997). In most cases, there is no evidence for unusual trauma; however, at Duvall, the known "foreigner" had been scalped and was the only body displaying such evidence (Dunnell 1980a).



Figure 125. **Isotopic data for locales where foreigners have been identified as part of the burial assemblage.** The filled symbol specifically indicates a "foreigner" at Roseberry Farm.

CONCLUDING REMARKS

Demographic data, although limited, are not consistent with the notion that specialized maize-based subsistence systems occurred as a response to population growth. Late Woodland populations are sparsely represented, but there is no evidence that population size or density increased prior to the appearance of maize farming. Nor is there any indication that resource depletion, driven by increased population density, was a causative agent. Thus, even as interpretations, such accounts are without warrant. Population in the region apparently increased significantly only *after* maize became the dietary staple. Once maize farming systems were established, particular subsistence trajectories in some areas may have been influenced by demographic factors, especially by competition among human groups and perhaps by competition with animals for cultivated resources.

CHAPTER EIGHT: RESOURCE AVAILABILITY AND TECHNOLOGY

The availability of new resources and the adoption of new subsistence technologies may have altered the selective environment in which Ohio Valley populations lived. Accordingly, it is relevant to consider evidence for variation in the appearance of maize-dominated subsistence systems that could reflect resource availability and technology. Reexamination of the published literature unfortunately has uncovered little by which to evaluate these hypotheses.

NEW RESOURCES

It has already been suggested that Eastern Eight-Row represents a variety of maize that evolved elsewhere in the East and was introduced into the Ohio Valley just prior to the appearance of maize-based farming systems (Wagner 1987). In this scenario, as a productive "new" resource well-adapted to the length and temperatures of the growing season, it rapidly replaced the traditional crops and became the subsistence focus. As has been noted (Fritz 1990, 1992; Wagner 1994), however, there is little evidence to support this scenario. There are simply not enough measurable fragments of maize from secure Middle and early Late Woodland contexts to establish definitively whether or not early maize in the Ohio Valley was morphologically different from Eastern Eight-Row. Similarly, we don't know enough about prehistoric maize varieties to predict what other kinds of evidence might be relevant (e.g., variation in the distribution of settlements across environments that might reflect different growing requirements). Thus, in the absence of better morphological data, this possibility cannot be evaluated further.

The common bean is another plant that, from all available archaeological evidence, was introduced into the region during the early Late

Prehistoric period (Figure 126). Low frequencies combined with a low likelihood of carbonization might have made an earlier introduction of beans archaeologically "invisible." Future research which involves processing more sediments to acquire larger archaeobotanical assemblages, combined with AMS dating of individual specimens, may allow the timing of the introduction of beans into the study region to be better established.

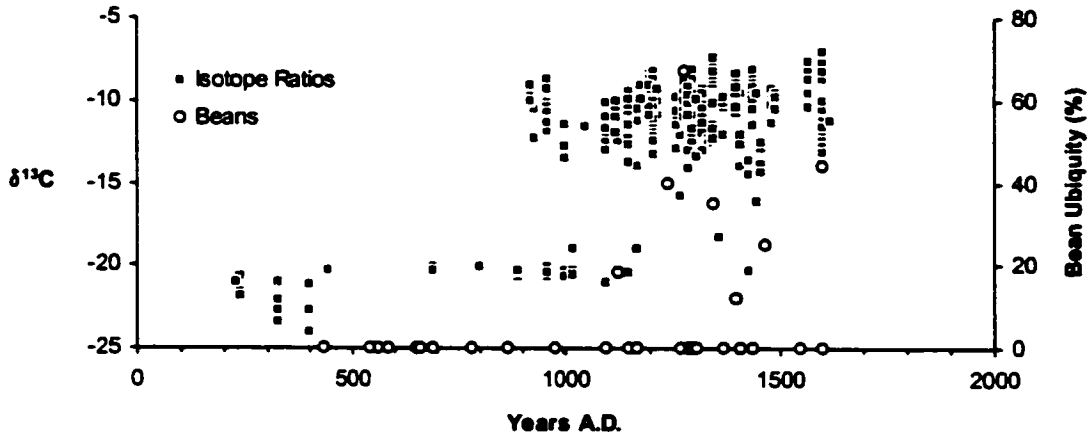


Figure 126. **Ubiquity of beans and stable carbon isotope ratios in the Ohio Valley.**

That Ohio Valley populations apparently flourished on a diet that was highly dependent on maize, on its own a nutritionally-inadequate crop, may be partly due to bean and/or meat consumption. Beans provide a protein that is nutritionally complementary to maize (Kaplan 1971, 1973; Katz et al. 1975). Specifically, when eaten together, the high lysine and adequate tryptophan contents of beans offset deficiencies of those amino acids in maize. In contrast to beans, animal meat is a concentrated, high-quality protein source that alone largely meets amino acid requirements.

Whether bean, meat or some combination of the two, was the protein complement in a maize-based diet should be distinguishable isotopically, even though the data to do so are not currently available. Levels of bean consumption

may be indicated by stable nitrogen isotopes in human skeletal tissues[57] (Ambrose 1987; Katzenberg et al. 1995; Schwarcz et al. 1985); demonstration of bean consumption using collagen may be somewhat complicated, though, by the complexity of nitrogen metabolism, isotopic variation in protein sources, and potential contributions by wild leguminous resources.

Analyzing the stable carbon and nitrogen isotope chemistry of individual amino acids like lysine is potentially more informative. Since lysine is an essential amino acid, it must come from the diet; isotope analyses indicate that essential amino acids experience relatively minor fractionation between consumption and tissue synthesis (Abelson and Hoering 1961; Hare et al. 1991; Macko et al. 1983). Figure 127 outlines how $\delta^{13}C$ and $\delta^{15}N$ ratios of lysine might be expected to vary given different dietary sources. The degree of enrichment and/or depletion will depend upon the total lysine contribution of all resources. If significant amounts of maize and beans were consumed together, lysine should be only slightly enriched in ^{13}C (because maize will contribute a fraction of the lysine,

		C source	
		C_3 resources	Maize
N source	Nonleguminous resources	^{13}C depleted ^{15}N enriched	^{13}C enriched ^{15}N enriched
	Beans	^{13}C depleted ^{15}N depleted	^{13}C enriched ^{15}N depleted

Figure 127. **Expected patterns of stable carbon and nitrogen isotope compositions of the amino acid lysine reflecting primary dietary protein sources.**

[57] Legumes are depleted in ^{15}N relative to most terrestrial protein sources and increased bean consumption should be reflected by lower $\delta^{15}N$ values.

the majority coming from the C_3 beans), but depleted in ^{15}N. If significant amounts of meat (or other protein-rich C_3 resources) and maize were consumed, lysine again should be only slightly enriched in ^{13}C, but enriched in ^{15}N.

Reiterating from Chapter Four, it is unlikely we will ever know quantitatively the contributions of maize, beans, or meat to prehistoric diets. Under some circumstances, however, we may be able to establish variation among individuals in the relative consumption of some resources. The expectations developed here for the amino acid lysine is one approach through which the dietary consumption of beans might be assessed.

PHENOTYPIC CHANGE

Rather than the introduction of a new variety of maize, changes in any number of features (e.g., increased storability, yield, or resistance to cold or drought stress) of the existing plant may have made it a superior crop (Rindos and Johannessen 1991). Unless such phenotypic changes are also reflected morphologically, it will be difficult to show that they occurred, let alone what those changes were. Research on modern maize varieties has begun to identify the functions of various genes (Dowswell et al. 1996). In the future, DNA analysis of prehistoric samples may allow different genotypes to be distinguished and the phenotypic implications of those variants to be identified. In the absence of genetic data, changes in the depositional context of maize remains may supply some information about potential phenotypic changes; sufficient data to address this aspect are not available.

TECHNOLOGY

Technological changes may have increased the net yield of resources like maize. One can imagine many new technologies (e.g., tools,[58] field preparation, scheduling, or resource processing) that might have made resources more predictable, made handling more efficient, made storage more reliable, or made the product more nutritious; any of these might have increased replicative fitness sufficiently to cause subsistence change. Testing these hypotheses may require the identification of new or altered technologies, engineering analyses to examine how the technological change functioned, and assessments of how the replicative fitnesses of the populations using it were affected.

FIELD PREPARATION

Weedy plants such as plantain (*Plantago*), purslane (*Portulaca*), bedstraw (*Galium*), carpetweed (*Mollugo*), grasses (Poaceae), panicgrass (*Panicum*), morning glory (*Ipomoea*), and nightshade (*Solanum*) are commonly found in disturbed areas and fields that would be created as part of a swidden farming system. Thus, variation in the intensity of field preparation may be evidenced by the frequency of these noneconomic weed seeds recovered in the archaeobotanical record. Average ubiquity values (cumulative ubiquity/number of weed taxa present) were calculated for each locale with data available to do so. As Figure 128 shows, the average ubiquity of weed seeds increases through time ($\rho = .648$; $p = .023$). Although some points appear to differ considerably from predicted values, none are statistical outliers.

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[58] Although some tools (e.g., hoes) are identifiable in the archaeological record, apparently many were made of wood and were not preserved. A consideration of variation in the tools used for subsistence activities requires functional analyses that are beyond the scope of this research.

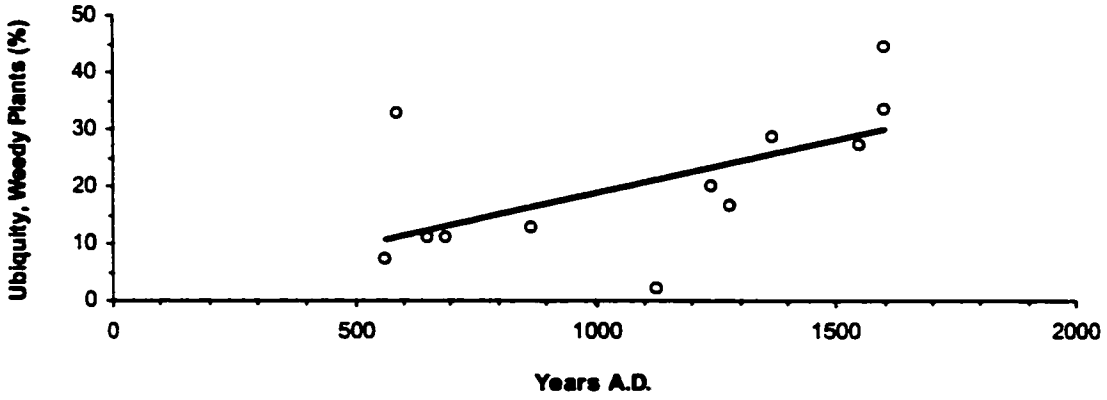


Figure 128. **Average ubiquity of seeds from weedy plants over time.** Data presented in Appendix B.

Charred wood remains from taxa such as hackberry (*Celtis*), redbud (*Cercis canadensis*), honey locust (*Gleditsia triacanthos*), Kentucky coffeetree (*Gymnocladus dioica*), red mulberry (*Morus rubra*), pine (*Pinus*), black cherry (*Prunus serotina*), black locust (*Robinia pseudoacacia*), sassafras (*Sassafras albidum*) and grape (*Vitis*) are often used by archaeobotanists as indicators of disturbed landscapes. Changes in the proportion of land in various phases of swidden farming may be evidenced by changes in ubiquity of such taxa. When the system involves long fallow periods, for example, second growth taxa may be quite abundant in the landscape; as farming intensifies and fallow periods become shorter, the abundance of second growth taxa may decrease.

Figure 129 plots the average ubiquity values (cumulative ubiquity/number of second growth taxa present) calculated for charred wood from each locale with available data versus age. The scenario of decreasing length of fallow periods over time is supported by the data, although the relationship is not statistically significant ($\rho = -.714$; $p = .071$). I note two reservations. First, the number of locales with wood charcoal ubiquity data is quite small, particularly for the Late Prehistoric period. Second, the two Late Prehistoric locales shown in Figure 129 are Goolman and DeVary (Figure 130), argued by the excavators to be

winter hunting camps; although maize remains were recovered there, the relevance of these locales to arguments about the nature of prehistoric swidden systems is questionable. Clearly, more data are needed. Some additional data are already available, but they are not published in formats that allow ubiquity values to be calculated.

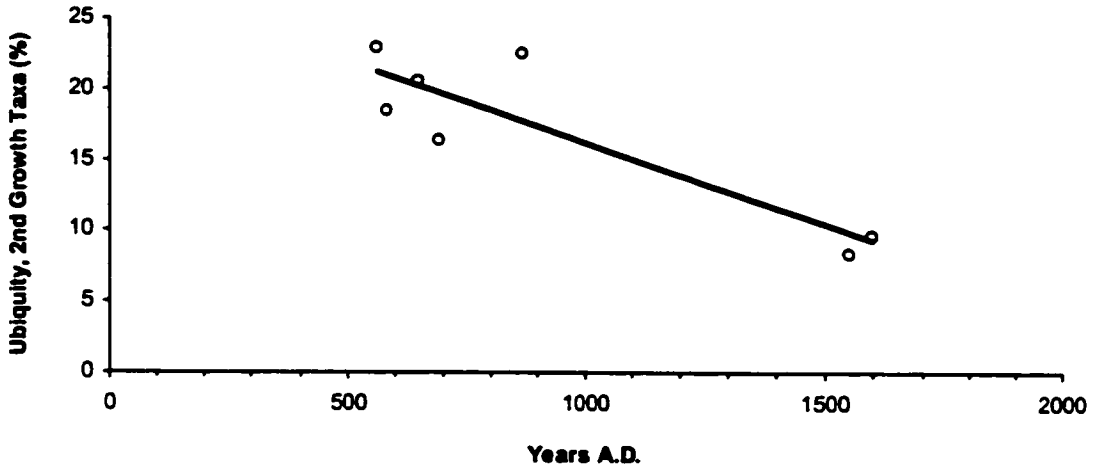


Figure 129. **Average ubiquity of charred wood from disturbed/second growth taxa through time.** Data presented in Appendix B.

As indicated in Chapter Seven, the abundances of faunal taxa that prefer disturbed or mature forest habitats may also be indicative of changes in the landscape associated with the spread of maize-oriented swidden systems. Although variation in the environmental situation of locales could obscure systematic change in the abundance of disturbed forest/forest edge fauna, holding environmental location constant over time (e.g., multiple assemblages of different ages from a single locale or assemblages from several locales in the same area) does not produce a clear pattern.

As noted earlier, the abundances of two taxa (turkey [*Meleagris gallopavo*] and opossum [*Didelphis marsupialis*]) changed over time (Figure 124). Although those data were presented and discussed within the context of competition suppression, they also are consistent with expectations of environmental change.

Both taxa prefer habitats (e.g., open woodlands and mixed vegetation) that would be created by swidden systems. The increased proportion of turkey and opossum in Late Prehistoric faunal assemblages, then, might be due to an increase in those preferred habitats as a consequence of greater areas of land involved in the swidden system. Deer populations may have increased similarly in response to habitat alteration; this is one possible reason for the lack of evidence for faunal resource depletion (Chapter Seven).

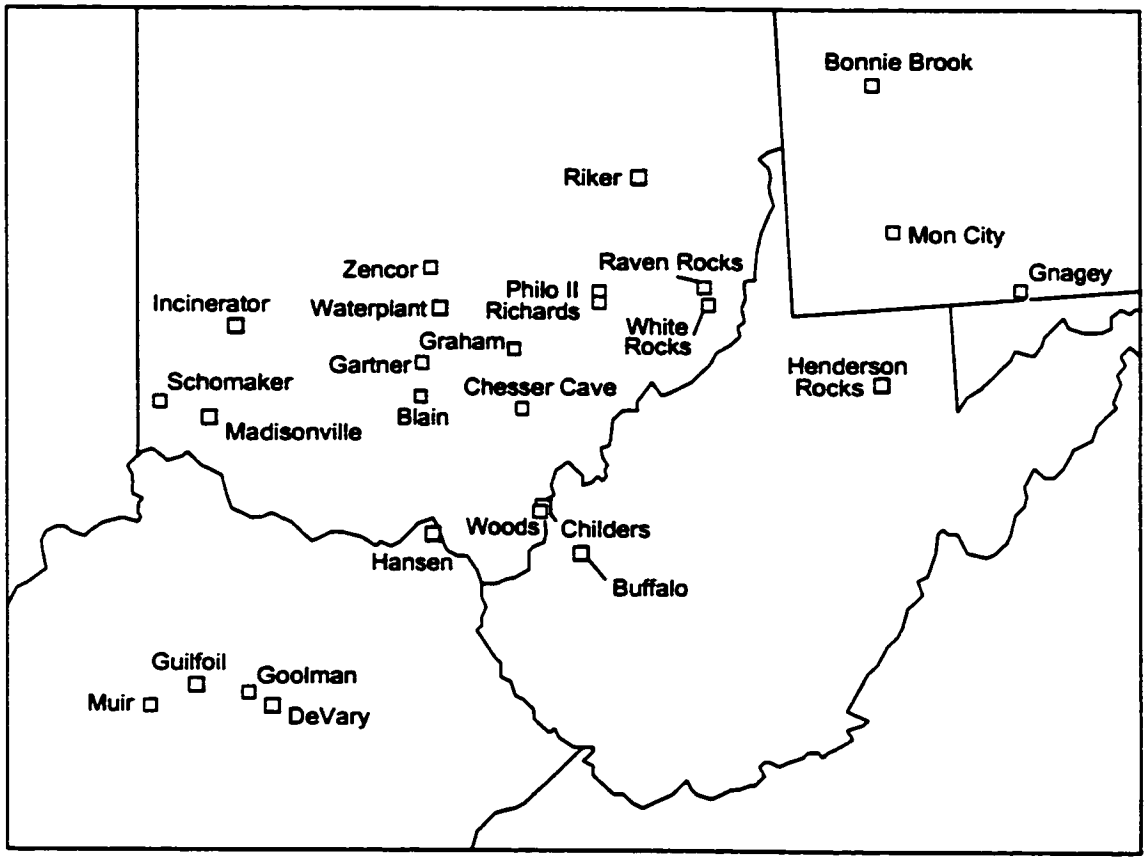


Figure 130. **Ohio Valley locales mentioned in the text of this chapter and/or indicated in tables or figures.**

SCHEDULING

Changes in seasonal resource scheduling may be reflected by variation in the resources exploited. The contents of individual stratified trash-filled storage pit features at Schomaker show seasonal variation in faunal exploitation (Cowan et al. 1990). Based on two of those features, deer and turkey reached their highest frequencies among faunal remains deposited during the late winter and deer continued to dominate throughout the rest of the annual cycle; fish and aquatic mammals increased in abundance during the spring; and by summer, fish, hellbenders (*Cryptobranchus alleghaniensis*), and turtles were important subsistence resources. Cowan et al. (1990) commented that the suite of animals used during spring and summer months could have been obtained near the village, perhaps reflecting labor commitments required by farming maize. This sort of analysis, when based on a larger sample of features and extended to other locales, can potentially provide critical details on seasonal variation in faunal exploitation.

Changes in seasonal subsistence activities may also be identified using archaeobotanical assemblages. It is generally assumed that various plant resources were acquired in the season in which their fruits ripen: spring (maygrass [*Phalaris carolina*], honey locust [*Gleditsia triacanthos*]), summer (blackberry [*Rubus*], blueberry [*Vaccinium*], plum and/or cherry [*Prunus*]) and fall (goosefoot [*Chenopodium*], sumpweed [*Iva annua*], sunflower [*Helianthus*], squash [*Cucurbita*], sumac [*Rhus* spp.], wild grape [*Vitis* spp.], erect knotweed [*Polygonum erectum*], pawpaw [*Asimina triloba*], and nuts). Figure 131 shows the average ubiquity of these seasonal classes for Ohio Valley assemblages. The average ubiquity of plant resources obtained during the spring decreased considerably and fall resources increased in the Late Prehistoric period. Surprisingly, the increase in fall resource ubiquity cannot be due to the high ubiquity of maize in Late Prehistoric assemblages, as that plant was not included in this seasonal analysis.

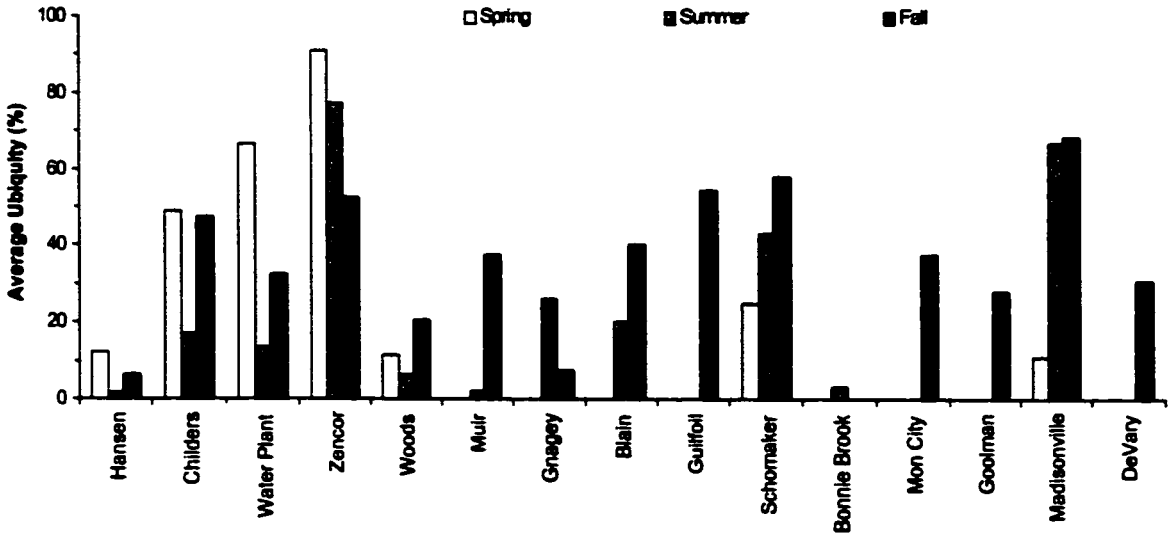


Figure 131. **Average ubiquity of seasonally-acquired plant resources in Ohio Valley archaeobotanical assemblages (arranged temporally).** Data presented in Appendix B.

Since white-tailed deer have a well-documented, seasonally-restricted birthing period (late May – early June), their ages at death have implications regarding the season of death. Published age data are available for deer from eleven assemblages (with at least 15 animals represented). Age was typically estimated on the basis of tooth eruption sequences and wear; although the dentition classification of Severinghaus (1949) was cited as the basis for most analyses, the ranges of reported age classes differ, making comparisons difficult. Presumably, this is an artifact of the known-age comparative materials available to each analyst. To resolve this problem, the data were converted to areal histograms of frequencies of animals by age class.

Figure 132a plots the relative abundance of all aged deer captured in each season from the eleven Ohio Valley assemblages with age frequency information. The seasonal exploitation of these deer appears to be quite even. The 95% confidence intervals are large, overlapping completely between seasons for all but one assemblage. That assemblage, Buffalo, is the only one that shows

significant differences in the exploitation of deer, with greater emphasis on autumn and winter kills. The marginal differences within and between many assemblages, including those argued to be fall/winter hunting camps, are not significant given potential sampling error.

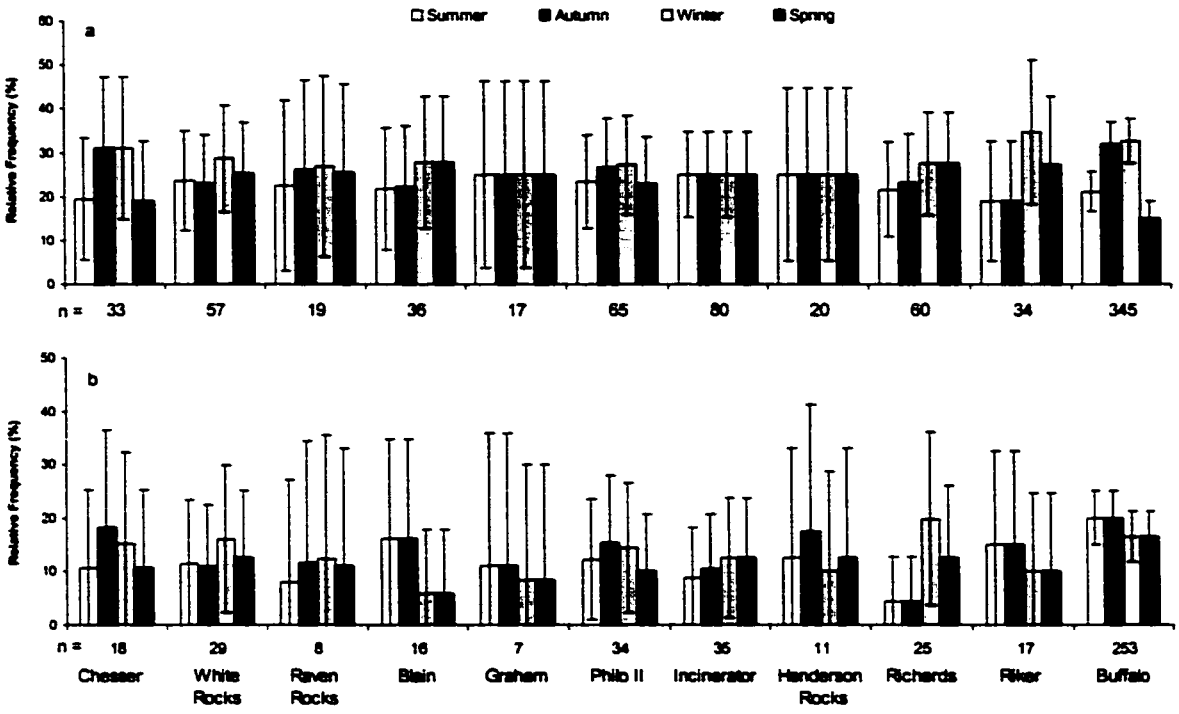


Figure 132. **Season-of-death for deer from Ohio Valley assemblages.** (a) all deer; (b) deer ≤ 2 years of age. Error bars show 95% confidence intervals.

Because ages can be more precisely assigned to younger deer, the seasonal distribution of deer aged two years or less might be more revealing. While reducing noise introduced by older, less precisely aged deer, this practice significantly decreases the sample size and increases the 95% confidence intervals such that no patterns in seasonality of acquisition are visible (Figure 132b). Such large potential sampling errors prevent more detailed examination of patterns of seasonal exploitation such as that observed by Guilday (1971) at Buffalo, where the summer kills were primarily young animals and the winter kills were predominantly mature animals.

PROCESSING

Changes in processing technology could have had a huge impact on subsistence. For example, ethnographically, there is a strong relationship between high maize consumption and the presence of alkali processing technology. Katz et al. (1975) found that many groups who grow maize and depend upon it as a dietary staple, also rely on alkali treatment (soaking or boiling the maize with lime, wood ash or lye) in processing it. This processing technique, said to soften the pericarp (outer kernel), decreases the quantity of protein available, but most importantly, it also significantly increases the quality of bioavailable protein in maize.[59] Populations who rely on maize prepared with alkali do not exhibit symptoms of pellagra or protein-energy malnutrition that is common among those who do not use alkali treatment (Katz et al. 1975; Srikantia 1982a). Although certainly worthy of consideration, the use of alkali processing technology may be difficult to identify archaeologically. Experimentally, different processing techniques (including alkali processing) distort kernel dimensions differently (King 1994); perhaps future work along those lines will identify morphological criteria by which alkali-treated maize can be recognized. Other subtle archaeological evidence may be present as organic residues adhering to the interior surface of ceramic sherds, or perhaps in the trace element composition of human skeletal materials (Brenton 2000; Buikstra et al. 1989).

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[59] Experiments conducted on animal models indicate that alkali treatment may also decrease significantly the nutritive value of maize by reducing the content of necessary vitamins (e.g., thiamine and riboflavin); animals restricted to pure alkali-treated maize diets fail to thrive and begin dying sooner than those on pure, but untreated, maize diets (Gontzea and Sutzescu 1968). Thus, although alkali treatment may improve the protein quality of maize, vitamin losses must be offset through other foods in the diet.

STORAGE

The implementation of a new storage technology could have a profound impact on subsistence. A more efficient and/or reliable storage technology could increase the value of some resources by extending their availability into periods of relative resource shortage and, with respect to cultivated plants, ensuring seed for the next planting season. Few data are available archaeologically about how resources were prepared for storage. In the Middle Valley, at least, maize was often removed from the cob and stored as loose grains in pits lined with bark or grass (Mills 1904). Relatively little information exists about how resources were actually kept. Of particular interest, though, is the observation that storage technologies differed between Middle and Upper Valley subsistence systems. In the Middle Valley, storage technology was subterranean; four semi-subterranean facilities have been reported at one locale (Buffalo) in the sample. In contrast, semi-subterranean facilities dominated in the Upper Valley (Hart 1995); subterranean storage features were much less common there.

A detailed analysis of variation in storage technology among the locales considered here is prevented by several potential problems. The most critical one involves inferring feature function from published reports. Few researchers provide the criteria by which they determined feature function. For example, it is not clear how storage pits were distinguished from other pits. A feature's form does not appear to consistently reflect its function, nor are its contents always a reliable indicator of its original function. With respect to feature form, features are commonly truncated by the plowzone, thereby eliminating the one crucial piece of evidence that could distinguish storage features – the pit opening. With respect to feature contents, most pits had no function when they entered the archaeological context, i.e., they had been abandoned. If a feature successfully met its function as a storage facility, then it should have been emptied of the contents it was originally built to hold; it would then be subject to erosional

filling or trash-dumping events that were unrelated to its primary function. In this regard, Mills (1906:61) wrote:

> "The refuse pits surrounding the tepee to the north were perhaps the most interesting in the village, for here abundant evidence was found showing that the refuse pits were originally intended and used for a storehouse for corn, beans and nuts, and perhaps, for the temporary storage of animal food, etc., and afterwards used as a receptacle for refuse from the camp. For some time I was of the opinion that the large cistern-like holes were dug for the express purpose of getting rid of the refuse, but as the explorations progressed I soon discovered their real purpose by finding the charred remains of the ears of corn placed in regular order on the bottom of the pit; and I was further rewarded by finding pits in various sections of the village containing charred corn, beans, hickory nuts, walnuts, etc., which had been stored in the pit and no doubt accidentally destroyed."

Indeed, DeBoer (1988) remarks on the unlikelihood that pits were ever dug for the purpose of disposing of refuse, simply because that entails considerable effort for a problem that is more easily solved. A pit's function as a trash receptacle was probably just its terminal use.

Few reports provide sufficient details by which to evaluate variation in feature form that might reflect changes in storage technology. Available data on Middle Valley storage pits indicate that most such features are cylindrical (straight-sided with flat bottoms), with bell-shaped pits running a distant second. Interestingly, the incidence of bell-shaped storage pits appears to be temporally-restricted to the late part of the early and the early part of the middle Late Prehistoric periods (Figure 133). In terms of storage efficiency, a bell-shaped pit would be slightly more advantageous than a cylinder because its surface area:volume ratio is lower, but it would take greater effort to construct. Although bell-shaped pits may result when the sides of cylindrical pits are cleaned (DeBoer 1988), that they are restricted in time suggests this may not adequately explain their incidence. If these bell-shaped pits were produced during pit cleaning, they

might be expected to be distributed more evenly through time; settlements with bell-shaped pits do not seem to have been occupied over longer durations than those with straight-wall pits.



Figure 133. **Incidence of straight-walled and bell-shaped storage pits at Middle Valley locales.**

Other changes in storage technology might be detectable in the average volume of storage pits. Unfortunately, accurate calculations of pit volume are hampered by plow-zone truncation of the features. Assuming that the effects of truncation are distributed randomly across locales, Figure 134 plots variation in pit volume among Middle Valley locales; two Upper Valley locales with subterranean storage pits are shown, as well. The data show an increase in the average volume of storage pits between the Late Woodland and early Late Prehistoric periods, with a subsequent decrease during the latter part of the middle and late Late Prehistoric periods. Although there could be many factors at play here, it is worth noting that the roughly coincidental climatic change toward cooler and moister conditions might have reduced the reliability of subterranean storage.

Archaeologists generally regard subterranean storage facilities as largely successful, since most pits are filled with eroded sediments and garbage.

Primary deposits are preserved rarely.[60] In the absence of fire, if stored materials in a pit had deteriorated due to pest infestation or moisture and were simply left to decompose, the pit would fill with secondary materials. No evidence of the pit's storage function would have been preserved, just as if it had been emptied by human consumers. The best evidence for the overall success of these features lies in their consistent and broad distribution through time and across environments in the region and elsewhere in eastern North America.

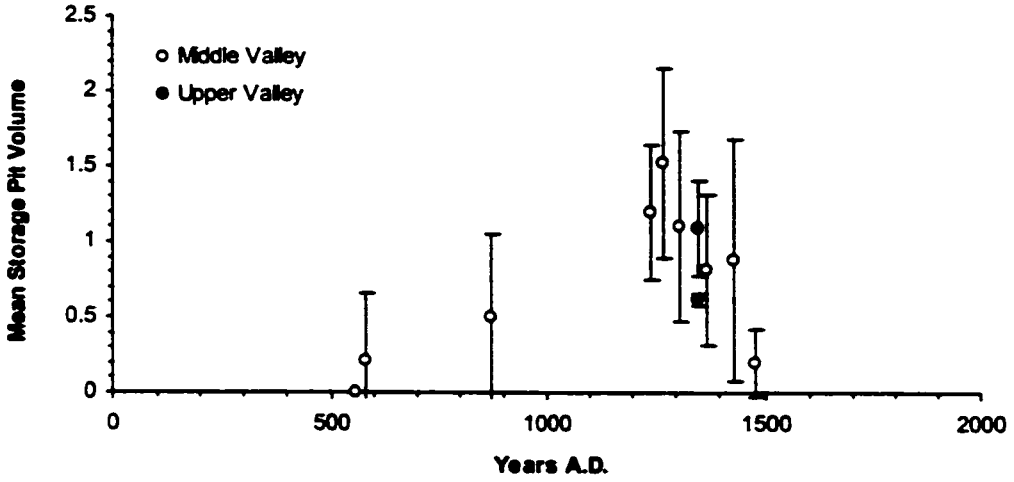


Figure 134. **Mean storage pit volume (m^3) in Middle and Upper Valley locales.** Error bars indicate one standard deviation. No corrections for plowzone truncation are included. Data presented in Appendix B.

As noted above, Upper Valley storage technology was dominated by semi-subterranean storage facilities and subterranean pits are uncommon. The semi-subterranean features appear archaeologically there as circular/oval/pear-shaped, postmold-lined, shallow pits; the posts apparently provided a framework to

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[60] Mills (1904) reported that 20% of the storage pits he examined at the Late Prehistoric Gartner site contained *in situ* charred materials, the original contents of the pits. He attributed the charring to fire blown accidentally into the pits. Hooton and Willoughby (1920) noted that corn was often stored after parching or charring and that conflict between groups may have resulted in setting fire to one's competitors' storage pits.

extend storage capacity above ground, as well as to enclose and to support a roof over the facility. The attribution of a storage function to these features is based on excavations by Cresson (n.d., cited in Dragoo 1955) in Somerset County, PA, who occasionally found their floors lined with charred bark and grass, and containing charred plant remains (maize kernels, cobs and nuts).

Hart (1995) has identified trends in the form and location of semi-subterranean storage features through time. He attributes changes in the location of storage features to changes in social complexity and control over resources. This is, of course, untestable speculation. Increases in the size and elaborateness (including the use of bigger posts and wall trenches) of storage features through time are viewed as indications of the increasing importance of stored resources in subsistence systems. Figure 135 plots average feature area (because of the potential for above-ground storage, storage facility volume is not accessible) for Upper Valley locales where such data are reported. Unfortunately, no data are available for locales occupied during the Late Woodland period by which to examine changes in feature capacity as subsistence changed. Although storage feature area does increase through time among some locales (consistent with the observations of Hart [1995]), this does not occur uniformly. In particular, features from locales in the Chartiers Creek area remain relatively small and may even decrease in size through time. Why these locales might show a different trend is not known.

CONCLUSIONS

Accounts that rely on changes in the resources or in the subsistence technology available to explain subsistence change in the Ohio Valley have been considered here only briefly. Most require data that are largely unavailable at this time, but that could be acquired with further research.

Plant and animal remains are consistent with the notion that farming systems intensified over time, that the amount of land involved in swidden systems

increased and that the length of fallow times decreased. Native plant resources available during spring and summer months were apparently utilized less frequently during the Late Prehistoric period than before and animals exploited during those seasons tended to be locally available ones. Together, these data suggest increasingly greater energy was expended in maize field preparation, maintenance, and perhaps protection. Populations of the Upper and Middle Valleys relied on different storage technologies and different trajectories in mean storage capacity are evidenced.

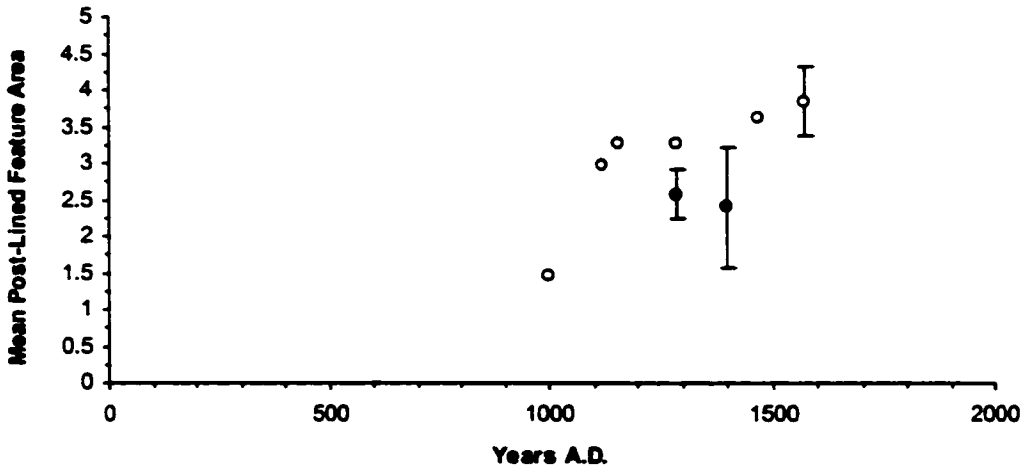


Figure 135. **Mean area (m^2) of semi-subterranean storage features in Upper Valley locales.** Error bars indicate one standard deviation. Chartiers Creek locales are gray-filled. Data presented in Appendix B.

Based on the available data, I cannot conclude that either available resources or subsistence technology were a *cause* for subsistence change associated with maize farming. If anything, the documented variation in these parameters would seem to reflect the *consequences* of that subsistence change. Clearly, though, more data are needed to thoroughly evaluate some aspects of this hypothesis.

CHAPTER NINE: SOCIAL CONTEXT

The final set of scenarios to examine regarding the appearance and spread of Ohio Valley maize-based subsistence systems involves an appeal to the social context of resource use. Most of the scenarios of this sort that have been proposed previously rely on variables that lack empirical relevance and, consequently, they cannot be evaluated scientifically. For some scenarios, though, hypothetical cores can be derived that allow empirical testing. For others, the empirical bases of speculations can be evaluated.

OUTSIDE INFLUENCE AND POPULATION INTRUSION

The once popular (e.g., Caldwell 1971; Mayer-Oakes 1955b; Prufer and Shane 1970) notion that the appearance of maize farming in the middle and upper Ohio Valley was a consequence of migrating Mississippians is no longer a defensible position. Continuity has been established for both historical and functional attributes, linking Ohio Valley Late Woodland and early Late Prehistoric groups in a continuous developmental trajectory.[61] Importantly, that the subsistence systems of Ohio and Mississippi Valley populations are so different (Rossen and Edging 1987; Wagner 1987) is evidence that the former did not acquire

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[61] Rafferty (1974) makes a good case for the local development of the Fort Ancient tradition. Stylistic attributes for several unrelated artifact types from Woodland and Late Prehistoric contexts in northern Kentucky seriate together, indicating a single continuous historical tradition. Furthermore, changes in functional attributes (e.g., settlement pattern and subsistence base) did not coincide with stylistic changes as might be expected if they all arrived as a suite as the migration hypothesis suggests. In addition, she points to an 80 mile geographic gap in settlement between the lower Ohio Valley Mississippian and middle Ohio Valley Fort Ancient traditions that is inconsistent with the migration hypothesis.

"maize agriculture" as a package from the latter.[62] The record of isotopic diet in the Eastern Woodlands also argues against the notion that maize farming was brought to the Ohio Valley by populations of the Mississippi Valley. Although limited by small samples, the available isotopic records from west and south (Figure 8) of the study region do not support a commitment to maize in those areas significantly earlier than in the Ohio Valley.

In contrast to current archaeological opinion, Sciulli (1998) has pointed to features of deciduous dentition as possible evidence for a migration of people into the study region during the Late Woodland period. He found significant differences in the incidence of double teeth and three (of 57) other morphological variants[63] between pre- and post-Late Woodland populations of the Ohio Valley. Although the apparent association of dental and dietary change implies that there may be a functional explanation for the increase in those dental variants, Sciulli notes that deciduous teeth are limited in their functional exposure and consequently they are not under a lot of selective pressure. Citing the apparent homogeneity of Eastern Eight-Row maize and abrupt changes in subsistence and settlement as indicating an "introduction" of these attributes from a southern or western source, he tentatively suggests that the changing features of the deciduous dentition are likely due to gene flow that may have accompanied this introduction.

Sciulli's interpretation of the subsistence and settlement records of the Ohio Valley is decidedly outdated and cannot be treated as evidence of gene flow. Additionally, most archaeologists believe that *if* Eastern Eight-Row did come to the Ohio Valley as a developed maize race, it came from the Northeast, not the

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[62] Probably the most critical difference between the two subsistence systems involves the role of EAC plants after maize farming was established – EAC plants apparently continued to play a significant role in subsistence systems of Mississippian populations, whereas they did not among Fort Ancient populations.

[63] The specific variants that differ are um1 cusp number, lm2 deflecting wrinkle and C7 (Sciulli 1998).

South or the West. Even so, changes in the deciduous dentition must be accounted for. Although one can imagine how an increase in the use of maize-based weaning foods might have changed the relative selective pressures on deciduous dentition, it is not clear at all how the particular variants at issue might have affected the fitness of the individuals bearing them. Perhaps these variants are pleiotropic, i.e., they are selectively neutral, but linked to other traits that do have fitness consequences. Although Scuilli (1998) is correct in noting that Late Woodland populations (which are underrepresented in his sample) will be crucial to resolving the issue, more detailed information about the geographic and temporal distributions of the variants, along with engineering analyses of the functional significance of the variants, are also required.

North of the study region, where lake resources (e.g., fish) are isotopically enriched above the isotopic background of C_3 terrestrial resources (Katzenberg 1989), the record of isotopic diet is more complicated. Slight isotopic enrichment that could reflect relatively low levels of maize consumption is not as clearly distinguished from consumption of other enriched resources as it is in other areas of the East. Nevertheless, Katzenberg et al. (1995) suggest that maize consumption in southern Ontario is isotopically detectable by A.D. 700 and that it gradually increased until roughly A.D. 1400 (Figure 8). The earliest radiocarbon dates on maize fragments north of the study area are certainly old enough for those populations to have been a source for Ohio Valley maize (Crawford et al. 1997). There is no evidence, however, for the transmission of other traits from north of the study region until much later in the prehistoric sequence (ca. A.D. 1300).

As noted in Chapter Two, sometime after A.D. 1300, some people may have entered the Ohio Valley from northwestern Pennsylvania and north-central Ohio. This inference is supported by nonlocal characteristics in ceramic assemblages at several Upper Valley and a few Middle Valley locales. Stable carbon isotope data from individuals at a few of the Upper Valley locales identified as

intrusive indicates their diets were more depleted isotopically than other, presumably indigenous, groups in similar physiographic and competitive situations (Chapter Seven). That these individuals evidently consumed less maize over much of their lifetimes is consistent with what we know of isotopic diets of more northern populations. As Figure 8 shows, Late Prehistoric individuals from southern Ontario and the Western Basin of Lake Erie were more depleted generally than individuals from the upper Ohio Valley.

Finally, the possibility of contemporaneous occupations of individuals with distinctively different subsistence systems in southwest Ohio is raised in Chapter Five. There appears to be continuity in material and thus it seems unlikely that populations of established maize farmers simply "expanded" into that area (as they apparently did at Slone [Dunnell 1972]). Alternatively, it seems more likely that the local populations varied in subsistence: some became specialized and others remained generalized. Larger samples are necessary to understand how individuals with differing subsistence systems were distributed across the landscape there.

CULTURAL MEANING AND RITUAL

The notion that maize was initially a "ritual" crop in the Ohio Valley stems largely from the contexts in which purportedly early remains were found by archaeologists. Prior to the late 1970s, far more reports of maize came from Middle Woodland mounds than habitations of the same age.[64] Since mounds are a commonly recognized part of the Hopewell phenomenon and since they often contain evidence for elaborate mortuary activity, it is generally assumed that subsistence remains recovered from mounds were also of ceremonial or ritual import. As Chapter Three notes, though, notions like "ritual" are not useful in a scientific

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[64] This may be a sampling problem, since both the number of excavations and the volume of dirt removed from mounds vastly outnumber those at domestic sites.

evolutionary framework and suffer from the same explanatory problem as "social status," at least in an archaeological context. When "ritual" is forwarded to account for an observed pattern, it simply relabels that pattern rather than explaining it; theoretical linkage between the pattern and "ritual" is lacking and it relies on our common cultural background to make the mental leap.

Like in habitation contexts, plant (and animal) remains in Middle Woodland mounds and earthworks could reflect the natural dispersal of materials ("background"), remnants from resources used at or near the locale ("nonwasteful" use), or they could reflect the costly deposition of items as part of the mortuary elaboration ("wasteful" use) [Dunnell 1989; Kornbacher and Madsen 1999]). The spatial distribution of remains, the contexts in which they are found, and other artifacts with which they are associated probably provide the best sources of information by which to determine why such remains are there. Even so, this is a probabilistic endeavor at best.

Figure 136 shows the location of Middle Woodland and Late Woodland archaeobotanical assemblages relevant to a consideration of the distribution of early maize in the study region. Maize fragments are exceedingly rare in both Middle Woodland and early Late Woodland deposits in the Eastern Woodlands;[65] they are infrequently present in archaeobotanical assemblages and, when present, their relative abundances are quite low. This pattern is probably due to a combination of low levels of plant usage and a low probability of maize carbonization and preservation (cf. Hart 1999a). Before we can make any statements about the rarity of early maize, though, we need to be certain that a large enough sample of botanical remains has been recovered and identified from

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[65] With the application of AMS dating to individual specimens (e.g., Conard et al. 1984), the ages of many purportedly Middle Woodland maize fragments have been shown to be more recent than initially believed. For example, maize fragments from the Middle Woodland McGraw village were dated directly and found to be more recent than their associations with other materials imply (Smith 1992b).

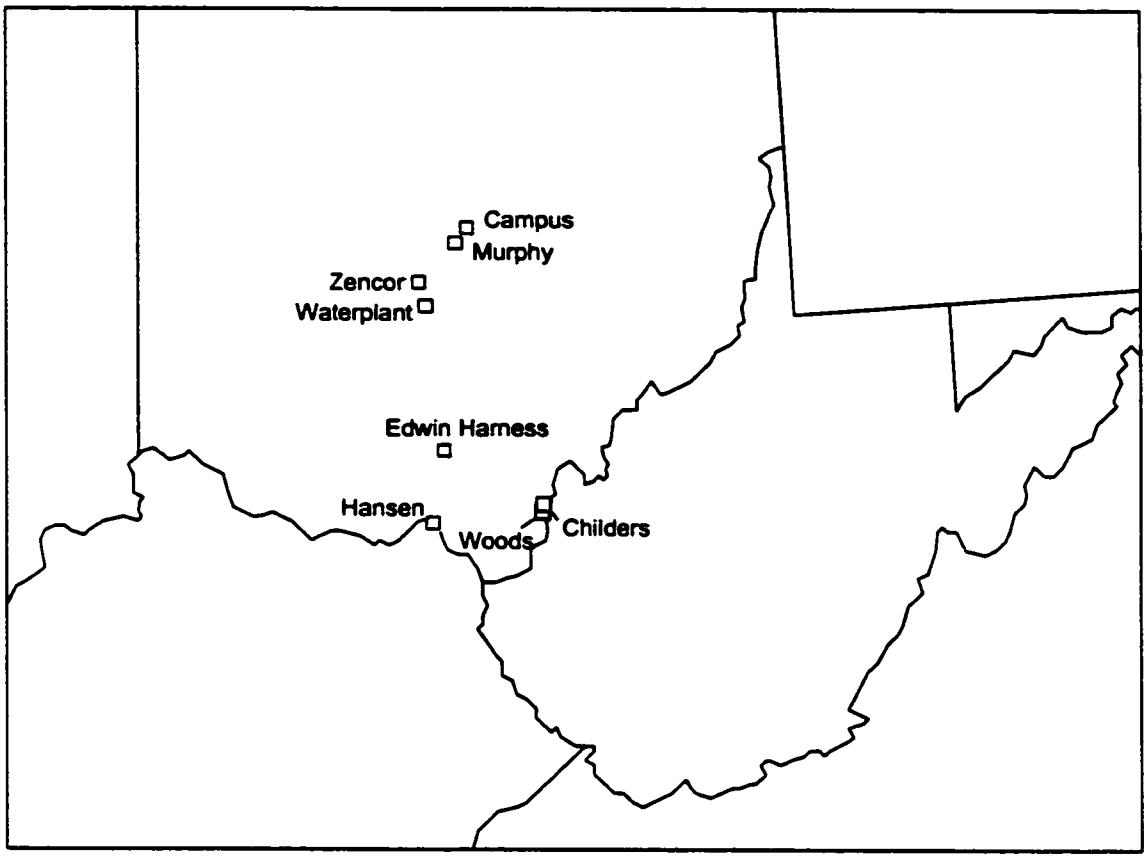


Figure 136. **Ohio Valley locales mentioned in the text of this chapter and/or indicated in tables or figures.**

those locales where it is apparently absent (i.e., if maize was present in such deposits, it would have been recovered). To examine this sampling issue, Figure 137 plots the estimated maximum proportion of maize that could be present, and yet remain undetected at $p = .05$, for several Middle Woodland and early Late Woodland charred seed assemblages where maize has not been recovered.[66] From this, maize fragments should not be encountered unless maize accounted for more

[66] Beals et al. (1945) presents an equation for estimating sampling error based on the size of the sample and the proportion of the material of interest. I used that equation to determine the maximum proportion of maize remains that could be present in a sample, but be considered absent (i.e., 0%), given the size of the charred seed assemblage for each locale.

than 0.3 – 0.7% of the assemblages. Notably, these estimates are consistent with the proportion of maize in charred seed assemblages actually recovered from the (Middle Woodland) Edwin Harness and (early Late Woodland) Childers deposits.

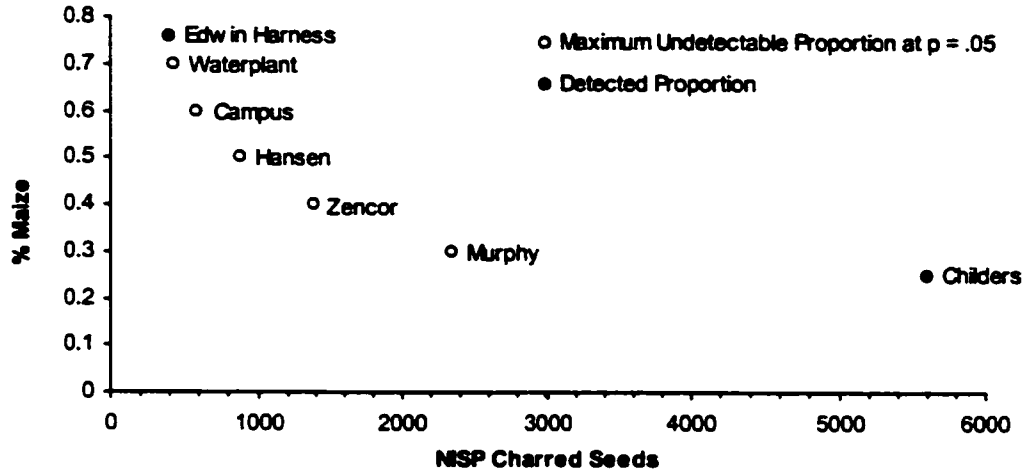


Figure 137. **Estimated maximum undetected proportion of maize fragments in charred seed assemblages from Middle Woodland and early Late Woodland contexts.** Actual maize frequencies shown for Childers and Edwin Harness. Estimates determined using equation of Beals et al. (1945); the accuracy of these estimates is limited because the normal approximation to the binomial distribution is poor for very small and very large proportions. Botanical data from Lopinot (1988), Smart and Ford (1984) and Wymer (1987, 1990).

To find rare fragments of maize, many liters of sediments may need to be examined to recover a sufficiently large botanical assemblage. At the Holding locale (shown in Figure 1), for example, 19 maize fragments were recovered after more than 5,000 liters of sediment were processed via flotation (Riley et al. 1994). Table 10 presents the amount of sediments processed to acquire botanical assemblages from several Middle Woodland and early Late Woodland deposits in the Ohio Valley where maize was undetected. Also shown are estimates of the amount of sediments that should be processed to establish (at $p = .05$) that maize

occurs at a level less than 0.25% of each of those charred seed assemblages.[67] For these assemblages, the amount of sediments examined are not adequate to state conclusively that maize was absent (< 0.25% of the charred seed assemblage).

Table 10. The average charred seed densities (counts/L sediment) for archaeobotanical assemblages lacking maize shown in Figure 137, amounts of sediments processed to obtain those assemblages, the estimated amount of sediment necessary to determine maize is less than 0.25% of the charred seed assemblage at $p = .05$, and the percent deficit between the amount of sediment processed and the amount required.

	Charred Seed Density (#/L)	Sediments Processed (L)	Estimated Amounts (L)	% Deficit
Murphy	17.3	135	202.4	-33.3
Campus	23.4	25	149.6	-83.3
Zencor	12.27	113	285.4	-60.4
Waterplant	10.82	39	323.5	-87.9
Hansen	0.84	1051.5	4182.1	-74.9

In the Ohio Valley, the only maize find that is clearly Middle Woodland in age is from the Edwin Harness mound.[68] Maize fragments at Edwin Harness have been recovered from three features: fill associated with a bundle burial, a stratum under the main clay floor of the mound, and burned material (not *in situ*) on the clay floor of the mound (Greber 1984). Table 11 lists the reported contents of those features. Of those features with maize remains, Features 45 and

[67] Again, using the equation of Beals et al. (1945), it was established that a botanical sample size of 3500 charred seeds would be required to know that maize was present in a proportion of less than 0.25%. Using the published number of seeds/liter of sediment, the number of liters of sediment required to reach 3500 seeds was determined.

[68] No old maize has been found in Middle Woodland habitation sites in the study region, but relatively small charred seed samples have been recovered for most (Wymer 1987, 1994).

60 contain artifacts (e.g., mica fragments, cut *Busycon* shell) that are frequent components of the Hopewell mortuary phenomenon. Thus, at least some materials in some of the features with maize are common examples of "waste." Although obvious subsistence "wastes" (e.g., perforated, often burned, canines [Shane 1984]) were recovered from the mound deposits, they were apparently not found in the features containing maize.

Consistent with the composition of charred posts recovered from the mound floor, *Carya* and *Quercus* dominate the wood charcoal samples; other wood taxa contribute minor amounts to the samples from most features (Smart and Ford 1984). There is no reason to believe that the wood charcoal samples reflect anything other than the remains of burned construction timbers and use of locally-available fuel wood at the mound locale. That is, the wood taxa in those features appear to reflect both "wasteful" and "nonwasteful" uses of the resource.

Charred seeds occur sporadically and in low frequencies in the flotation samples at Edwin Harness. This led Smart and Ford (1984) to conclude that most seeds, including goosefoot (*Chenopodium*) and knotweed (*Polygonum*), were probably included accidentally (either from background or nonwaste sources) in most features where they occur. However, because the goosefoot and knotweed were found with a maize kernel (and some kernel fragments) in the bundle burial fill, they speculated that there the seeds may have been part of a mortuary offering (i.e., waste). When the seed assemblage from the bundle burial fill is compared with other features, though, it does not appear to differ from them with respect to those three potentially economic seeds (Figure 138). There is no evidence to support the claim that the plant remains in the bundle burial fill reflect a different source from the other features; the plant remains are not consistent with greater waste in that burial feature at Edwin Harness.

Table 11. Artifactual contents of features at Edwin Harness which contain maize (Greber 1984). Sediment volumes processed for these features were not reported and so it is not certain that assemblage size is comparable among them.

Material Type	Feature 45 burned material on clay floor	Feature 60 bundle burial	Feature 65 stratum under clay floor of mound
lithics:			
	mica fragments		fire-cracked rocks
	bladelet midsection		flint flakes
wood charcoal[a]:			
	Carya	*Carya*	*Carya*
	Quercus (white grp.)	*Quercus* (white grp.)	
	Quercus (red grp.)	*Quercus* (red grp.)	
	Castanea	*Castanea*	
	Acer	*Fagus*	
		Juglans	
carbonized seeds:			
	1 *Zea*	1+ *Zea*	*Zea*[b]
	1 *Chenopodium*	4+ *Chenopodium*	1 *Chenopodium*
	1 *Polygonum*	16+ *Polygonum*	10 unk. (egg shaped)
	3 Gramineae	8 *Euphorbia*	
		131 unk. (egg shaped)	
other:			
	fossil fragments	cut *Busycon* shell	
	mammal & bird bone fragments	terrestrial gastropod & naiad shells	

[a] Number of wood charcoal pieces identified from each feature range from 180 for Feature 45 to 20 for Features 60 and 65.

[b] Identification uncertain due to fragmentary condition of remains.

The archaeobotanical assemblages from the early Late Woodland Childers and late Late Woodland Woods locales are also relevant to this consideration. Recall from Chapter Two that Wymer (1994) noted differences in the intra-site distribution of maize between Childer and Woods that she argued reflect changes in social context. In brief, she found that the few maize remains recovered

were concentrated near the apparent center of the settlement ("apparent" center because an unknown amount of the deposit had been eroded by the river) at Childers, whereas at Woods maize remains were both more abundant and more equally distributed across that settlement. This distributional variation merits a closer look; fortunately, data are available to do so (Wymer 1990).

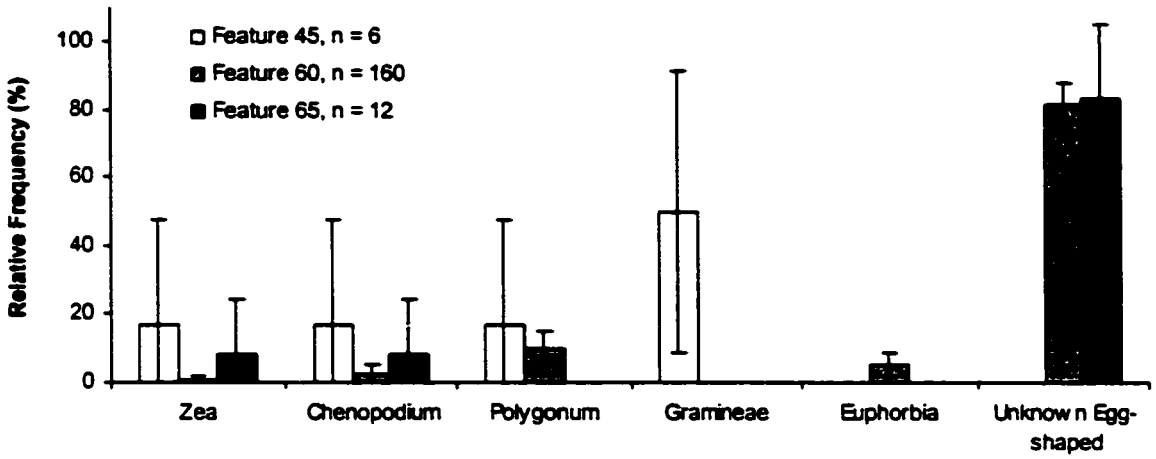


Figure 138. **Relative frequency of charred seeds from features at Edwin Harness that contain maize fragments.** Error bars indicate 95% confidence intervals.

Figure 139 shows the distribution of features with and without maize at the Childers and Woods locales.[69] Maize does appear to be much less evenly distributed across space at Childers than at Woods. Although differences in the distribution of maize remains between Childers and Woods could conceivably reflect some manner of change in the social context of maize use or deposition, other factors could also account for this pattern. For example, Ohio Valley settlements are often structured spatially with respect to functional classes; thus, the different distributions of maize remains may correspond to differences in intra-site functional

[69] The coordinates for two features (35 and 28) from Childers as reported in Table 9.3 (Shott 1990b) did not correspond with their mapped locations (Figure 9.8). I assumed the map was correct and changed the coordinates accordingly.

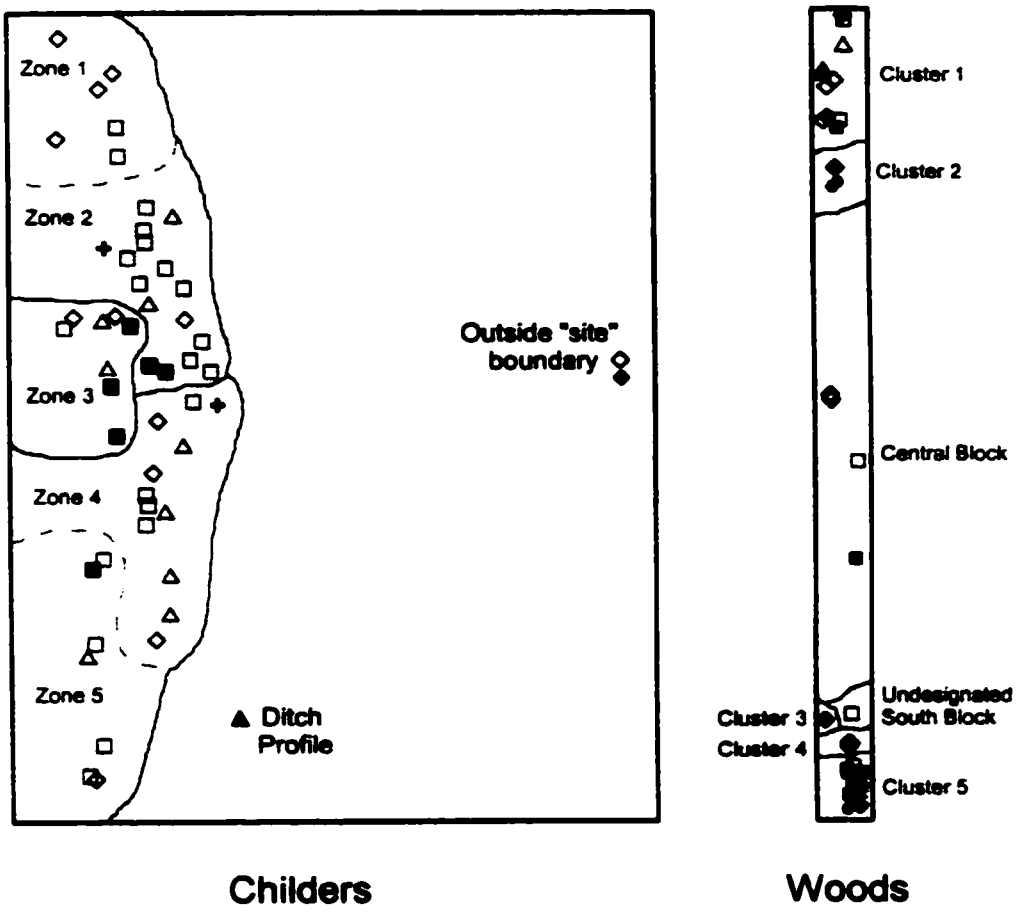


Figure 139. **Spatial distribution of archaeobotanical samples without (open symbols) and with (filled symbols) maize from Childers and Woods (not shown at same scale).** Hearths (◇, ◆), cooking/food storage (□, ■), burials (✚●), and other (△, ▲). Spatial groupings (zones, clusters and blocks) used by Wymer (1990) are indicated.

variation. In addition, features may vary with respect to how archaeobotanical remains were deposited or how they were preserved. Thus, it is important to consider how the maize remains at Childers and Woods are distributed across different classes of features.

Features were distinguished by Shott (1990b) on the basis of their formal dimensions. Those feature types were combined to create four feature classes that also incorporated descriptive information about their inferred functions.

This means there is not a strict correspondence between my feature class and Shott's formal types, but there are general patterns: hearths are mostly types 1 and 3; cooking and/or food storage features are mostly types 2, 4, 5, 14, and 16; burials are mostly type 6; and other features include all other types. Table 12 shows for the two locales how many features of each class were processed for archaeobotanical remains and how many of each class contained maize fragments. Even though archaeobotanical remains were analyzed for fewer features at the Woods locale, the number of features containing maize remains is considerably greater there than at Childers.

Table 12. Frequency of archaeobotanical samples and samples with maize among different feature classes at Childers and Woods.

Feature Class	Childers[a]		Woods	
	n	w/maize	n	w/maize
hearth	13	1	15	7
cooking and/or storage	27	6	14	8
burial	2	0	7	5
other	10	1	5	4
Σ	52	8	41	24

[a] To avoid empty cells, the burial and "other" feature classes from Childers were combined for statistical analysis.

In Figure 139, it is clear that most of the maize finds at Childers are from cooking/food storage features.[70] At Woods, maize remains are found frequently in all feature classes. These different patterns are apparent in Table 12. Log-likelihood ratio goodness of fit tests (using the G statistic) were used to assess the probability that the distributions of feature classes containing maize differed

[70] Neither of the maize-containing features outside the occupational area at Childers are cooking/food storage features; in order to compare statistically the Childers with the Woods data, they must be included. I note, however, that their relationships with the occupation at Childers are unclear.

between Childers and Woods; they do not differ significantly ($G = 4.338$; $.25 > p > .10$). For each locale, the distribution of feature classes containing maize does not differ from an even distribution (Childers: $G = 3.191$, $.25 > p > .10$; Woods: $G = 0.866$, $.90 > p > .75$). Similarly, the distribution of feature classes containing maize was found to not differ from the distribution of feature classes analyzed (Childers: $G = 1.572$, $.50 > p > .25$; Woods: $G = 0.583$, $.95 > p > .90$). There is no statistical evidence by which to support functional differences between Childers and Woods in the deposition and recovery of maize remains.

Also relevant to the notion of functional variation in maize use is the observation that, among the archaeobotanical samples analyzed, 83% of the features with maize from the occupational area at Childers and 96% of those with maize from Woods were filled with secondary deposits (the maize-containing feature at Childers with a primary deposit also contained secondary fill). Secondary fill came either from dumping episodes or was washed in; indeed, the contents of pit fill do not differ in kind or quantity from those of midden deposits (Shott 1990b). Consequently, the presence of maize in most archaeobotanical samples is probably unrelated to initial feature function. A similar conclusion was reached by Shott in his examination of feature contents (using various artifact classes) across his feature types (1990b).

If archaeobotanical samples from features are more-or-less random samples of the surrounding archaeobotanical population at the locale, then the spatial concentration of maize remains at Childers is a function of either differential maize use/discard or some manner of sample bias. Unlike situations elsewhere (e.g., Johannessen 1993a), there is no evidence for "special" discard of maize remains at Childers; other artifacts recovered in the maize-containing features at Childers were rather mundane. If the central area of the occupation was "ritually" important, it is not apparent in other data sets.

Maize is much rarer at Childers than at Woods. Only fourteen maize fragments were found in six features from Childers occupation; at Woods, 458 maize fragments were recovered. Thus, the distribution of maize remains at Childers may make sense when viewed from the perspective of sampling a rare item. The probability of finding rare items increases as sample size increases. If the secondary fill of these pits is a relatively random sample of midden debris, large pits should have a greater likelihood of containing maize; flotation samples, even if they are volumetrically standardized, will be more likely to include maize if they sample large pits rather than small ones. Features with maize do tend to be larger (in terms of volume) than those lacking maize at Childers, but not at Woods (Figure 140), suggesting sampling as the prime determinant. Finally, as Figure 141 shows, large features tend to be concentrated in the apparent center of the occupation at Childers; thus, the apparent concentration of features with maize appears to be a function of sample volume.

If sampling accounts for the spatial pattern of maize remains recovered at these localities, we might also expect that the number of features with maize will increase as the density of features examined increases. At Childers, the frequency of features containing maize in spatial zones[71] defined by Wymer (1980) did not differ statistically from the frequency of features analyzed in those zones ($G = 3.3074$; $0.25 > p > .10$); the same is true at Woods ($G = 1.9168$; $.95 > p > .90$). The implication of these analyses of both feature density and size is that sampling cannot be rejected as an explanation of the distribution of maize fragments.

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[71] As indicated by the dashed lines in Figure 139, Zone 1 at Childers was combined with Zone 2, and Zone 4 was combined with Zone 5 to eliminate empty cells in the statistical analysis.

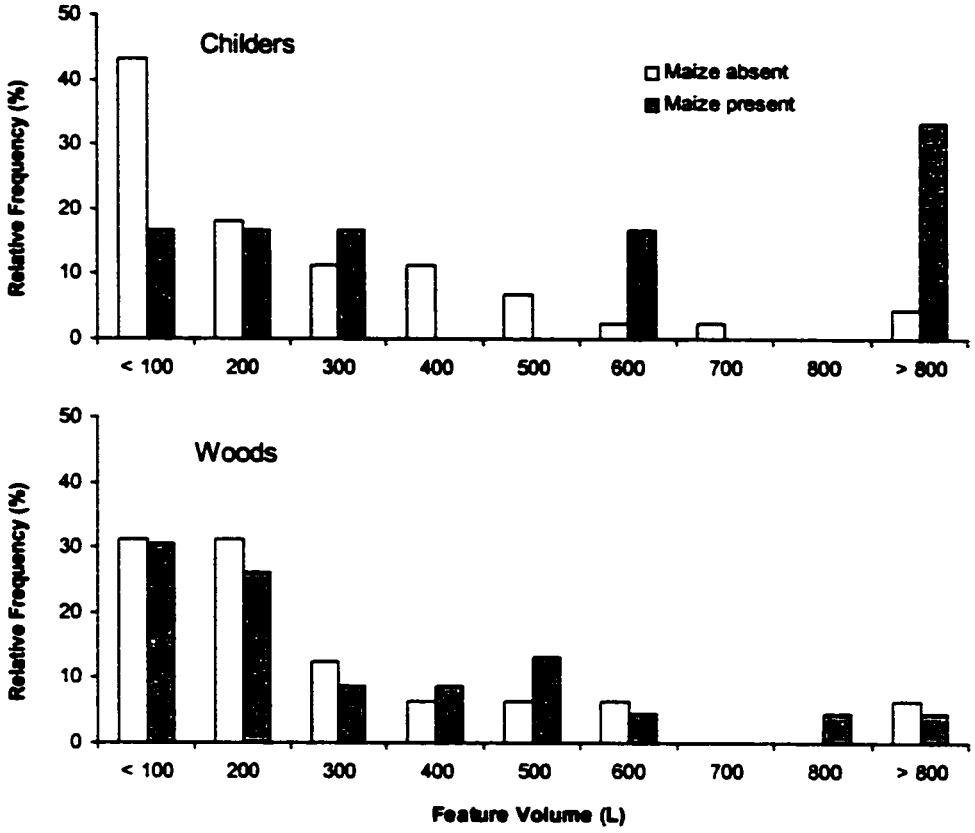


Figure 140. **Proportion of archaeobotanical samples with and without maize versus feature volume at Childers and Woods.**

CONCLUDING REMARKS

All of the evidence taken to mark the influence of social factors on variation in maize-based subsistence systems in the middle and upper Ohio Valley is either deceptive or can be explained by other factors. Migration is an unlikely mechanism to account for the spread of maize farming into and throughout most of the study region. Except for isolated cases on the eastern periphery of the area (e.g., Slone), artifactual evidence seems to indicate *in situ* changes to subsistence systems rather than wholesale replacement of them. Skeletal traits that *could* reflect gene flow into the region are not strong indicators of that mechanism;

additional data from Late Woodland skeletal populations are required to better evaluate such possibilities.

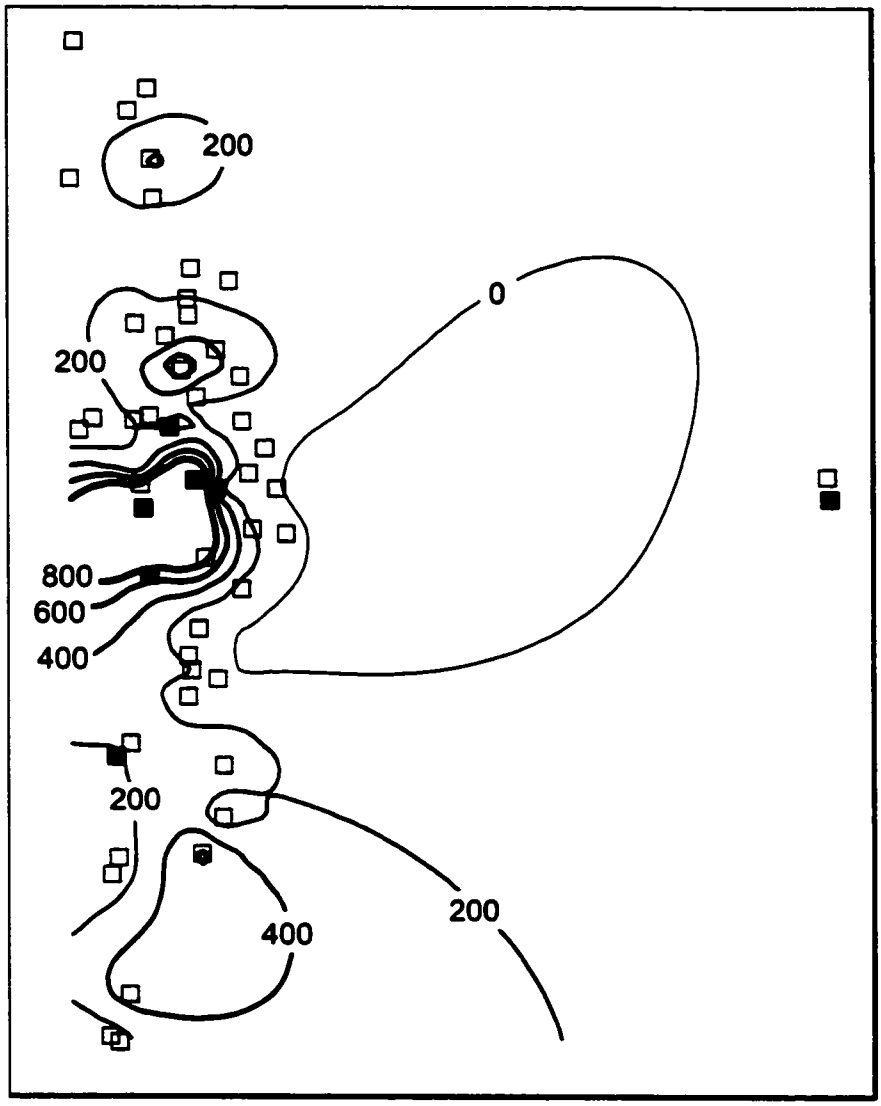


Figure 141. **Contour map showing the distribution of feature volumes (L) at Childers.** Symbols plot locations of features processed for archaeobotanical remains; filled symbols indicate features that contained maize.

Even though the notion of "ritual" is rejected as lacking explanatory relevance here, the evidence on which such scenarios rely on to explain the origin of maize use by Ohio Valley groups is found to be without empirical merit. More

detailed information, founded in larger samples, on the geographic, temporal and intrasite distribution of maize and other subsistence remains in archaeological deposits, particularly from Middle and Late Woodland contexts, is necessary to explain the record of early maize use.

CHAPTER TEN: SUMMARY AND CONCLUSIONS

This research set out to explain the appearance and spread of maize-dominated subsistence systems in the middle and upper Ohio River valley. Accounting for the prehistoric trajectories of maize-based farming systems in the Eastern Woodlands is not a new endeavor. Indeed, this effort is one of a large and growing bibliography of archaeological research concerning the appearance of farming systems there. This research is not, however, just an addition to a growing body of data. The approach I have taken here differs theoretically, methodologically and empirically from other attempts.

The appearance and spread of maize-based subsistence systems in Ohio Valley prehistory is a historical problem. To explain it in a scientific manner requires a scientific theory governing historical questions. Consequently, evolution (which is just that – a scientific theory governing historical questions) is the most appropriate theoretical framework for this research. As applied to archaeology, evolutionary theory can provide testable, historical accounts for all manner of prehistoric variation within a scientific (i.e., empirically testable) framework. Elements of both behavioral ecology and evolutionary archaeology are incorporated in this effort.

To date, many attempts to apply evolutionary theory to archaeological questions have been hamstrung by a failure to maintain the critical separation between the generation of variation from the sorting of that variation. In many cases, natural selection has been assumed to play a role in the former, but apparently not the latter (e.g., individuals were assumed to behave in certain ways because they had been "designed" to do so by natural selection and no subsequent consideration was accorded to selection). Such an approach is not consistent with the structure of an evolutionary explanation. This effort, by retaining natural selection as a sorting mechanism, is different.

Most previously-proposed accounts regarding maize-based subsistence systems in the Eastern Woodlands were developed within a post-hoc interpretive framework. That approach, along with other problems (e.g., lack of empirical sufficiency and theoretical warrant) significantly limits the scientific value of the resulting scenarios. In contrast, my research emphasizes empirical testing of multiple, theoretically warranted, hypotheses about the archaeological record of subsistence change. Even though the hypotheses considered here involve the same basic variables (climate, demography, resource availability and technology, and social context) as, and are even derived from, previous accounts, those accounts were not accepted unconditionally. Some scenarios were eliminated as untestable ethnocentric speculation; others were rephrased so as to be testable and consistent with evolutionary theory.

Different variables produce archaeological records that differ in several important ways (e.g., dietary composition, subsistence structure and content, environmental location, settlement structure). Thus, once legitimate hypotheses (i.e., ones that can be tested empirically, and, once tested, have implications for the rest of knowledge via their theoretical justifications) are developed and the kinds of data necessary to test them are deduced, it should be a simple matter to evaluate the roles of these variables in Ohio Valley maize-dominated subsistence systems. Extant data, however, were not adequate to test most hypotheses in even a minimal way. There were both theoretical and empirical problems that required resolution prior to hypothesis testing:

(1) Outside of special circumstances (e.g., the "abrupt" appearance of variants interpreted to reflect migration and population replacement), the archaeological literature has implicitly assumed a gradualist stance when discussing prehistoric subsistence change. The discipline's reliance on modal descriptions (e.g., mean $\delta^{13}C$ values) has served to reinforce this strongly-embedded

assumption. In an evolutionary framework, however, the distributional structure of variation is important to determining causation. By examining the distributions of measurements, rather than just means, the assumption of gradualism is avoided and the possibility of other and multiple transmission mechanisms can be considered.

(2) Subsistence and diet are inconsistently defined in the archaeological literature and, indeed, the terms are often used interchangeably. Since they apply to different scales, refer to different processes and require different kinds of data, it is important to carefully and consistently distinguish them. This is particularly important in an evolutionary approach because selection often occurs at the scale of the individual, whereas subsistence data generally reflect the combined results of actions of groups of individuals.

(3) Many published reports did not address the impact of diagenesis on Ohio Valley faunal assemblages. Since this research seeks to compare assemblages among different locales, it is important to control for those potential sources of error. I use several kinds of information (e.g., physical condition, sediment pH and texture, presence of calcareous tempers) to establish classes of comparable preservation.

(4) A comprehensive chronological assessment of the age of occupations in the region was lacking. Here, hundreds of previously-published radiocarbon determinations had to be closely evaluated, along with other temporal indicators, to establish chronological sequences for the middle and upper Ohio Valley. In

addition, ten new radiocarbon determinations on human skeletal materials of ambiguous age are reported.

(5) A detailed, relevant model of climatic change for the past 2000 years in the Ohio Valley was lacking. As part of this research, climate proxy data from several different sources (pollen, tree rings, beach ridges, borehole temperature profiles) and macrophysical climatic models are evaluated and integrated to produce a climatic model against which the archaeological record is compared.

(6) Current knowledge about stable carbon isotope metabolism has come from small laboratory animals (e.g., rats, mice) or large free-ranging herbivores, neither of which may be good animal models for the human condition. Results from a controlled feeding study using pigs, which have digestive systems physiologically similar to people, are reported here. A clear relationship between isotopic diet and bone chemistry in a good nutritional surrogate is demonstrated.

(7) The extant record of stable carbon isotopic diet among archaeological human skeletal remains from the study region was inadequate for establishing how maize-dominated subsistence systems appeared and spread. New isotope data, more than doubling the existing data set, were generated for this research. Samples were chosen to fill in temporal and geographic gaps in the existing record to the extent possible in a single project. Merging my new measurements with the existing isotope data produced a uniquely large, dense record of variation in isotopic diet.

SUMMARY OF RESULTS

The first direct evidence for significant maize consumption in the middle and upper Ohio River valleys dates to roughly A.D. 900, even though maize remains have been dated there ca. A.D. 300. Although it is commonly assumed that subsistence change followed a gradualistic model (i.e., maize gradually came to dominate subsistence systems over relatively broad areas more or less synchronously), there is no evidence for a gradual increase in maize intake in either place. Indeed, the Middle Valley provides clear evidence for the existence of two isotopically distinct populations at that time and throughout much of the prehistoric sequence. The Late Woodland sample from the Upper Valley is admittedly limited. When it occurred, subsistence specialization appears to have happened quite rapidly (within a generation) and at the margins of the study area.

A comparison of the isotopic record with the newly-developed model of climatic change for the region shows that the appearance of maize-based subsistence systems followed closely a change toward warmer, wetter climatic conditions. Although archaeologists are rightfully resistant to the notion that climatic change (or any other parameter) requires people to behave in particular ways, climate change certainly altered selective conditions. An episode of generally warmer and wetter conditions may have increased the net yield and predictability of the maize crop,[72] raising the economic potential of this resource relative to others (i.e., a change in "resource ranking"). Some groups responded by increasing their commitment to the plant; others did not. Those that did came to dominate the Late Prehistoric landscape, though to a variable degree and tempo.

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[72] Warmer conditions may result in earlier attainment of warm soil temperatures, which allows earlier spring planting. Warmer and wetter conditions during the growth cycle of maize may minimize the likelihood of moisture and temperature stresses, both of which can seriously impact yield and predictability of harvest by interrupting plant growth, reproduction, and grain maturation (Shaw 1983; Shaw and Newman 1991).

Maize ripens at a time when many resources are available. Thus, it seems unlikely that simply increasing the net productivity and/or predictability of maize can account for its rapidly increased dietary role. The advantage provided by a high yielding crop will be most significant when it can be stored until times of relative resource scarcity (i.e., late winter and spring). Successful resource storage requires both an adequate technology and amenable phenotypic characteristics. Unfortunately, neither of these attributes is well-known. Future efforts are needed to better document the characteristics of storage technology and to address the storability of maize. I suspect that changes in storage capability may ultimately prove to be the critical factor in explaining why maize consumption increased when it did, but without knowing the developmental trajectory of these variables, it is not possible to evaluate its role.

By the early Late Prehistoric period, maize contributed a significant proportion to the diets of *most*, but not all, individuals within the Ohio Valley. Interestingly, there is evidence for the maintenance of at least one population of non- or low-maize consuming individuals until at least A.D. 1450. The geographic distribution of isotopically-depleted individuals indicates one such population in southwest Ohio. This area is environmentally distinctive, both in the high incidence of treeless areas or "prairies" and in the high frequency of summer droughts. The "prairies" may have been abundant and predictable sources for a variety of wild resources; "prairie" soils might have been difficult to farm with swidden techniques, thereby reducing the efficacy of maize cultivation. The high frequency of summer droughts may have lessened the yield and predictability of maize crops in the area, as compared with other parts of the Ohio Valley. Depleted individuals from other Late Prehistoric contexts outside southwest Ohio have been identified, but so far they are relatively isolated cases.

Understanding the trajectory of maize farming systems in the Ohio Valley requires consideration of physiographic setting. Isotopic diets vary

significantly with respect to physiography in both the Middle and Upper Valleys. Individuals living in broad valley bottoms (which are generally characterized by greater ecological diversity and richness than narrow bottom and upland settings) consumed less maize than individuals in either narrow bottom or upland settings. The implication is that even though successful maize-farming systems established an artificial ecology, a maize agroecology, subsistence systems still mirrored subtleties of the local context.

The record of isotopic diet indicates that, once established, maize farming systems in the Middle and Upper Valleys followed different pathways, apparently as a result of different selective conditions. In the Middle Valley, $\delta^{13}C$ values appear to be stable through time until perhaps A.D. 1450, after which they decrease. Although this trend is consistent with expectations given initially warm and wet climatic conditions, followed by changes toward cooler and then drier conditions, the association is not tight nor statistically significant. A persuasive argument can be made that this pattern reflects instead a settlement change toward occupation of larger valley bottoms (cf. Graybill 1981), ecological situations where people tended to be less reliant upon maize.

In the Upper Valley, the geographic and physiographic locations of settlements varied as a consequence of deteriorating climatic conditions in the area (Johnson et al. 1989) and subsistence systems may have done so, as well. In upland situations, maize consumption increased even as climate became cooler and then drier through the Late Prehistoric period. This is counterintuitive, as a cooler and drier climate in the area would be expected to have reduced the quantity and predictability of maize yields; accordingly, individuals who consumed more maize should have been at a selective disadvantage under such conditions. Groups living in broad bottoms evidenced no mean change in isotopic diet, but dietary variation apparently increased. Climatic conditions and physiography, thus, cannot account

for all of the variation in isotopic diet documented among Late Prehistoric populations of the upper Ohio Valley.

There is no compelling evidence for an increase in the number of consumers prior to the appearance of maize farming. Age-at-death distributions indicate that fertility rates among maize farmers were high and thus, it is no surprise that the establishment of maize farming systems in the study region was followed by increases in local population density and apparent out-migration. Even though fertility apparently increased, there is evidence for "undernutrition" among maize farmers when compared with earlier populations. Although demographic growth could have resulted in the decreased availability of wild resources in local catchments, there is no clear evidence such a thing occurred. Expansion of secondary forest and forest edge habitats due to swidden cultivation and the availability of a dense resource patch (maize) probably allowed local population densities of many faunal taxa to increase, counteracting more intensive exploitation by people.

Intergroup competition apparently intensified as human population densities grew. One consequence of increased intergroup competition in at least some circumstances may have been a greater commitment to concentrated, locally attainable resources, particularly maize. In the Upper Valley, upland groups living in defensive situations (e.g., surrounded by palisades) were more reliant upon maize than those living in upland settings that lack the physical manifestations (e.g., palisades) of a defensive position and members of the former group consumed increasingly more maize through time. Intergroup competition apparently had little impact on maize consumption among bottomland populations in the Upper Valley, but this may be confounded by a high proportion of "immigrants" in the sample. Among Middle Valley populations, maize consumption was apparently greater among Late Prehistoric groups with higher frequencies of lethal injury; although

the incidence of lethal injury likely reflects competition, it is not clear whether the competitors were from the same community or another one.

FUTURE DIRECTIONS

To explain how and why maize came to dominate Ohio Valley subsistence systems requires additional effort. The first requisite is greater detail regarding the timing, tempo and structure of dietary change. Below are suggestions of what kinds of data are needed to meet that challenge:

(1) Stable carbon isotope analyses of human skeletal remains from Late Woodland contexts are especially critical. This research has pinpointed isotopically that the late Late Woodland period is the time during which this major subsistence change occurred. Unfortunately, few skeletal samples from that time have been analyzed and they do not reflect the diversity of settlement (and presumably subsistence) systems that were present. Although other individuals from this time may be curated in extant collections, they, too, likely represent a biased sample of large settlements and earthworks; research biases against small, dispersed settlements need to be addressed.

Geographically, it appears that maize-based subsistence systems first appeared at the margins, rather than in the center or at one end, of the study area. Such a pattern has important implications for explaining how and why such subsistence systems arose in the Ohio Valley (i.e., it eliminates the common notions that maize farming was introduced from some other place [e.g., the Mississippi Valley] and subsequently spread from the point of introduction throughout the region, or that maize farming was first adopted in those areas in which it was most productive).

Importantly, though, most of the limited late Late Woodland $\delta^{13}C$ data are from "marginal" areas. Additional samples that improve the geographic coverage for this time period need to be analyzed to ensure the distribution of early maize farming systems is not an accident of sampling.

That some individuals apparently consumed little or no maize, while other individuals in their community and/or in other nearby communities ate significant amounts, is an important observation with implications for understanding the spread of maize-dominated subsistence systems. In this research, isotopically-depleted individuals from Late Prehistoric contexts were rare.[73] Analysis of additional individuals to establish that that rarity is not a product of sampling bias and to better document the selective environments in which they lived is warranted. Although this research found a "concentration" of the apparently rare isotopically-depleted Late Prehistoric individuals in southwest Ohio, the sample is too small to establish how those individuals were related to isotopically-enriched ones in the area or what the nature and trajectory of populations lacking maize-dominated subsistence systems were.

Expanding the sample of environmental contexts is also crucial to documenting how and explaining why maize-dominated subsistence systems varied. For example, stable carbon isotope

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[73] How many individuals should be selected for chemical analysis is rarely addressed in the archaeological literature. Clearly, analysis of only a handful of individuals from each community is not sufficient to ensure that dietary variation has been characterized adequately. Using incremental sampling to determine how many samples should be analyzed is a better approach; when available, a minimum of 15 – 20 individuals will probably be necessary to provide a good estimate of dietary variation.

data need to be obtained from more individuals from various physiographic settings to be certain that documented relationships between physiography and subsistence are not fortuitous and to better establish how physiography and subsistence are related. In addition, there are large portions of the study area (e.g., parts of West Virginia and Kentucky) that are underrepresented.

(2) For those occasional individuals with "transitional" $\delta^{13}C$ values, documenting what those values represent will be critical. Distinguishing between a lifetime isotopic diet of -16 ‰ and two diets of -20 ‰ and -12 ‰ "averaged" analytically has important implications for understanding the trajectory of dietary change. Laser ablation isotopic analysis of demineralized bone thick sections, comparing "collagen" of different histological ages, might allow those possible dietary alternatives to be distinguished. I plan to examine the "transitional" individuals identified in this research accordingly.

(3) Although bioapatite has been argued to provide a better measure of C_4 consumption, particularly when C_4 consumption is low, "collagen" has been the only tissue analyzed in the Ohio Valley to date. Future efforts should be directed toward bioapatite purification and evaluation techniques. If $\delta^{13}C$ measurements that accurately reflect isotopic diet can be obtained for the bioapatite fraction of archaeological human skeletal remains from the region, they should be generated for Middle and Late Woodland skeletal remains.

(4) Radiocarbon determinations on human skeletal materials that have been analyzed isotopically will be important to clearly establishing the age of those remains. In some cases, where there

is evidence for multiple or long-term occupation of a locale, high-precision ^{14}C dates and/or fluorine analyses will be needed to establish the structure of dietary variation at any given time and/or the trajectory of change.

(5) Although the archaeobotanical record has proven to be an inaccurate indicator of maize consumption, documenting the presence and morphology of maize in Middle and early Late Woodland deposits may provide useful information about early maize populations. Because evolutionary explanations demand knowledge of variation, the presentation of morphological data must go beyond the modal descriptions typically reported. Since there is apparently significant isotopic variation in maize, isotopic analysis of more maize specimens will be important to understanding how that may have affected consumers' $\delta^{13}C$ values.

Once the trajectories of maize-dominated diets in the Ohio Valley are better established, those data can be arrayed against other parameters to determine causation. Each of the four groups of hypotheses considered in this research requires additional work to allow sufficient testing. Current descriptions are too coarse to allow all competing hypotheses to be distinguished. Although some new fieldwork will be required to address the needs described below, much can be obtained from theoretical refinement and analysis/reanalysis of existing collections:

(1) Climate. More and better climate proxy data from within and near the study area would be useful to further refine the climatic model developed here. Although it is the most critical kind of climatic information for explaining subsistence variation, temporal *variability* in climate is not well understood; most climate proxy data are poor sources of information about climatic variation. One

of the best and most relevant sources of local climatic information could come from isotopic analyses (e.g., $\delta^{18}O$, $\delta^{13}C$) of archaeological faunal and botanical specimens. A better understanding of how the yields and predictability of different plants, both cultivated and wild, are affected by climate will be critical to moving beyond simple correlation.

(2) Demography. Parts of the settlement record are poorly known. Collecting relevant settlement data should be a priority. For example, critical settlement data from Late Woodland occupations, when maize-dominated subsistence systems appeared in the region, were insufficient to determine the timing of population increase. Establishing the number of settlements, settlement size and roofed area for Late Woodland (and, to a lesser extent, Late Prehistoric) occupations is required to evaluate the demographic hypothesis. DNA analysis may allow the population trajectories of particular lineages to be traced, important to understanding the impact of diet on biological reproductive success, inter-group cooperation, and out-migration. In addition, systematic documentation of the presence and nature of defensive features is crucial for understanding changes in inter-group competition among populations.

Demographic data (e.g., age, sex) for more human skeletal assemblages (with assessments of biases) are required to better understand the impact of subsistence change on population structure, fertility and mortality. Some of the sex and age data currently available were generated prior to the development of more sophisticated techniques (e.g., DNA, histological analysis) for such assessments and thus those individuals should be

reanalyzed. Again, fertility among lineages may be tracked using DNA. The role of diet in mortality, especially childhood mortality, may be better understood using isotopic analysis to establish weaning times and diets.

Theoretical refinement regarding empirical entailments of the concept of "well-being" (Wood 1998) is necessary to transcend the "osteological paradox" and draw significant conclusions about nutrition and mortality among prehistoric groups. Estimates of stature (or better yet, raw measurements of bone lengths) and pathological observations, particularly for Late Woodland populations, are needed to better establish the relationship between undernutrition and subsistence change.

Turning to the geographic proximity of resource exploitation, necessary work will be multifaceted: chemical (isotopic and/or trace element) analysis of plant and animal remains to establish location of acquisition with respect to geological sources; for animals, mitochondrial DNA analysis can establish breeding populations, stable carbon isotope analysis can determine the degree to which they were competing with people for the maize crop, demographic data may indicate variation in the seasonality of acquisition for different segments of the population, size data may indicate changes in exploitation intensity, and the condition of remains (e.g., cutmarks, fragmentation, burning, disaggregation) may indicate variation in the use of animal resources.

(3) Resources and Technology. Genetic analyses of dehydrated maize specimens preserved in caves and rockshelters may produce information about at least some prehistoric populations of maize.

Perhaps closely-related historic races can be identified and some information about the growing requirements and yields of prehistoric maize can be obtained. A more detailed archaeobotanical record of early beans (requiring large, well-dated botanical samples), coupled with C and N isotope data from individual amino acids (e.g., lysine) might allow the role of beans in maize-dominated subsistence systems to be assessed.

Greater understanding of the physics and chemistry of storage technology, along with better data on the temporal and geographic distribution and the frequency of different kinds of storage features, may shed light on role of storage in maize-based subsistence systems. For example, this research suggests that bell-shaped pits were seemingly limited both temporally and geographically, but it is not at all clear why. Acquiring data on pit dimensions, which are not often reported, will be critical for understanding changes in storage capacity associated with subsistence change.

(4) Social context. Detailed assessments of the distribution of ceramic styles may provide evidence for intercommunity contact and the movement of people into and through the region. DNA analysis may allow the spread of lineages to be traced, while TL dating and seriation of ceramic assemblages will produce fine-scaled chronologies required to detect population movement. More large botanical and faunal samples from both Middle Woodland settlement and mortuary contexts will be necessary to establish how these resources functioned with respect to the Hopewell mortuary elaboration.

It is apparent that this research is only a first step toward providing a full explanation of how and why maize-dominated subsistence systems appeared and spread in the Ohio Valley. A lot more effort is required of us. As future research generates new data relevant to the problem, the details of this account may change. If we pursue the strategy outlined here, though, perhaps we can move from seemingly endless speculations, that vie for acceptance like political candidates, to a truly scientific account. Efforts that build on the successes and failures of hypothesis testing will refine our knowledge and produce evermore empirically powerful explanations. Only then will we make progress, not just work.

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APPENDIX A: ARCHAEOLOGICAL DATA AND CHRONOLOGY

Figures 142 and 143 map and Table 13 lists the 125 locales which comprise the selected sample for this research. Table 13 indicates, for each locale, the relevant kinds of published information available and the references from which those data were gleaned. This is a comprehensive sample of Late Woodland and Late Prehistoric archaeological locales in the study region with published information regarding faunal, botanical and/or human bone chemistry analyses. In addition, this study reports new bone chemistry data for many locales lacking such data.

The availability and quality of data sets vary across the locales that constitute the sample. That the availability of data varies is illustrated by a simple tally of the number of locales (out of 125 in my total sample) with published data about relevant archaeobotanical (n = 46), archaeofaunal (n = 55), and stable carbon isotope (n = 20) assemblages. New stable carbon isotope analyses are here reported for 64 new locales and for five of the 20 locales for which published stable carbon isotope analyses were already available (Figure 43). That data quality differs among these assemblages is easily appreciated, given that these assemblages are the result of excavations conducted over a 100-year time span, with greatly varying recovery techniques and different excavation goals.

CHRONOLOGICAL CONSTRUCTION

Efforts at establishing chronological control over the locales listed in Table 13 are presented here. After a brief consideration of the state of chronological systematics across the region, ages are evaluated, on a case-by-case basis, for assemblages recovered from the locales in my sample.

SYSTEMATICS

Our knowledge of prehistory across the Ohio Valley and through time is unevenly developed. In part, this reflects topographic variation and the relative ease with which some areas can be explored; in part, it reflects the nature of the

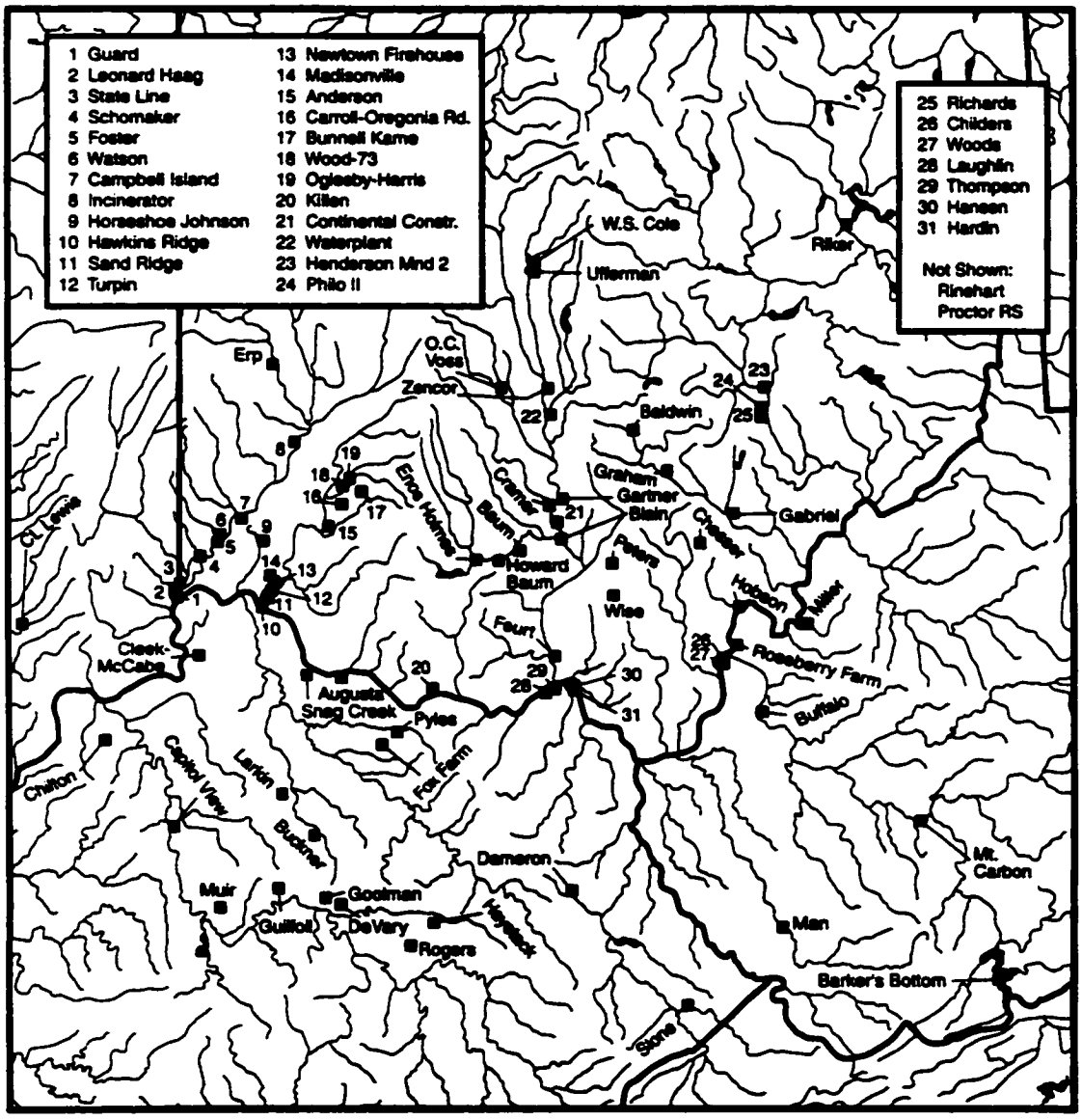


Figure 142. Middle Ohio Valley locales.

archaeological record, including researchers' interest in, and the relative visibility of, particular components; and in part, it reflects the availability of research support. Central and southern Ohio benefited from institutional support for archaeological exploration comparatively early (late 1800s and early 1900s). In contrast, archaeological research in the surrounding areas lagged, with most significant contributions waiting until Works Progress Administration (WPA) projects in the 1930s and '40s. As a consequence, not only is the prehistory of central and southern Ohio better known, but it also provided the basic temporal framework with which much of the prehistory of the surrounding areas is organized.

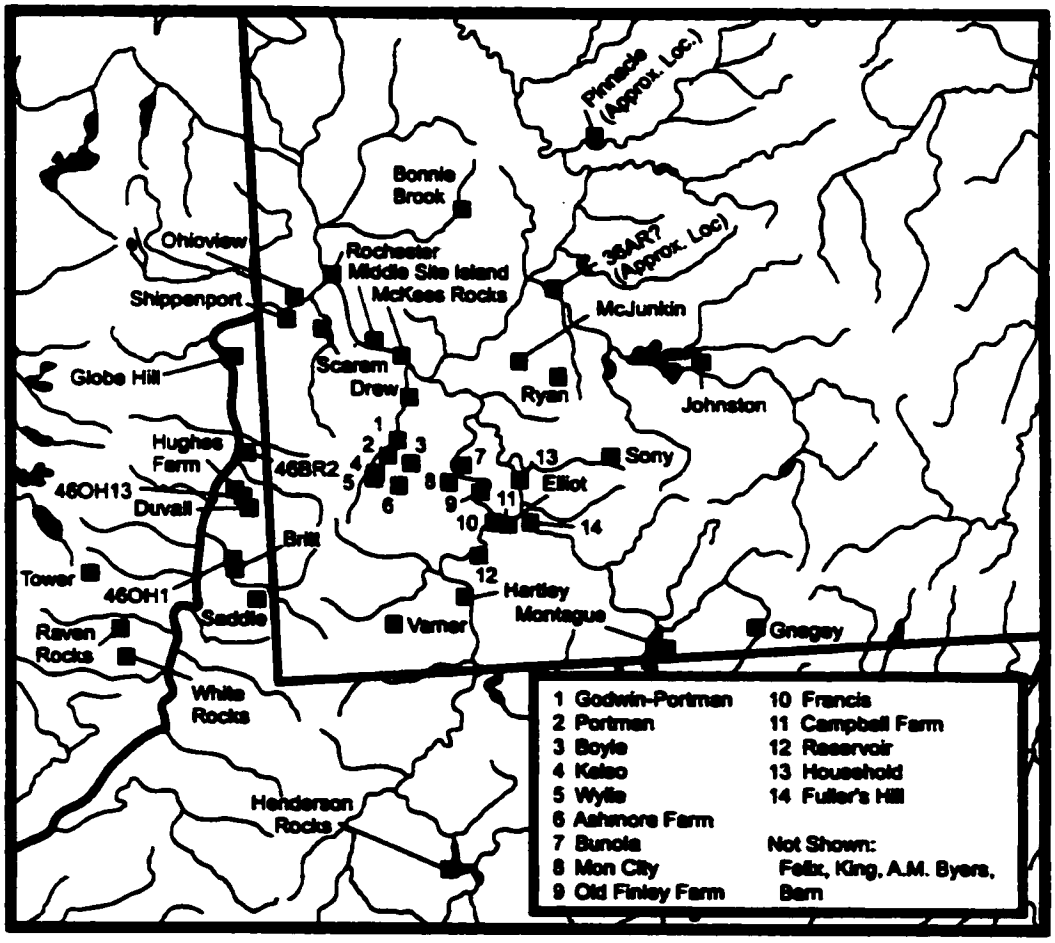


Figure 143. **Upper Ohio Valley locales.**

Table 13. Archaeological deposits, available data sets and references.

Name[1]	Number[1]	Data[2]	References[1]
near N. Vandergrift	36AR?	*BC*	--
--	46BR2	S, *BC*	Mayer-Oakes 1955b
--	46OH1	S, BC	Greenlee 1990; Mayer-Oakes 1955b
--	46OH13	S, BC	Farrow 1986; Greenlee 1990
Anderson Village	33WA4	S, F, B, *BC*	Essenpreis 1982; Wagner 1987
A. M. Byers	36BV?	*BC*	--
Ashmore Farm	36WH675	S, *BC*	Eisert and Boyce 1985
Augusta	15BK200	S, F, B	Breitburg 1992; Rossen 1992; Turnbow and Jobe 1992
Baldwin	33FA1?	S, B, *BC*	Goslin 1952a; Maslowski et al. 1995
Barker's Bottom	46SU3	S, F, B, BC	Applegarth et al. 1978; Dirkmaat 1978; Jones 1987; Maslowski, p.c.
Barn	36AL53	*BC*	--
Baum	33RO4	S, F, B, BC, *BC*	Mills 1902, 1906; Schurr and Schoeninger 1995; Wagner 1987
Blain Village	33RO49	S, F, B	Carr and Haas 1996; Galinat 1970; Kaplan 1970; Parmalee and Shane 1970; Prufer and Shane 1970
Bonnie Brook	36BT43	S, F, B, *BC*	Blake 1981; Herbstritt 1981
Boyle	36WH19	S, F	Nale 1963; Sciulli 1995
Britt Bottom	46MR29	S, BC	Dunnell 1970; Farrow 1986
Buckner	15BB12	S, BC	Schurr 1998
Buffalo	46PU31	S, F	Graybill 1981; Guilday 1971; Hanson 1975
Bunnel Kame	33CN7	S, *BC*	Brose and White 1979, 1983
Bunola	36AL4	S, *BC*	Mayer-Oakes 1955b; Sciulli 1995

Table 13 (continued).

Name[1]	Number[1]	Data[2]	References[1]
Campbell Farm	36FA26	S, *BC*	Herbstritt 1988; Johnson 1998; Michael 1981
Campbell Island	33BU2	S, F, B, *BC*	Cowan 1986; Shetrone 1923; Wagner 1987
Capitol View	15FR101	S, BC	Schurr 1998
Carroll-Oregonia Road	33WA86	S, F	Brose and White 1979, 1983
Chesser Cave	33AT692	S, F	Cleland and Kearney 1967a; Prufer 1967
Childers	46MS121	S, F, B, *BC*	Marwitt et al. 1986; Maslowski and Dawson 1980; Oetelaar 1990; Powell and Shott 1990; Shott 1989, 1990a; Wymer 1990
Chilton	15HY1	S, *BC*	Clay 1984; Funkhouser and Webb 1937
C. L. Lewis	12SH2	S, *BC*	Kellar 1960
Cleek-McCabe	15BE8,22	S, *BC*	Rafferty 1974
Continental Construction	33RO348	S, *BC*	Carr and Haas 1996; Sciulli et al. 1988
Cramer a.k.a. Kramer	33RO33	S, B, *BC*	Goslin 1952b; Ullman 1985
Dameron Rockshelter	15JO23A	S, F	Dirkmaat 1980; Vento et al. 1980
DeVary	15CK147	S, B	Turnbow et al. 1983
Drew	36AL62	S, F, B, *BC*	Buker 1970; Cutler and Blake 1976; George 1974, 1995)
Duvall	46OH16	S, F, BC	Dunnell 1980a; Farrow 1986
Elliot	36FA14	S, *BC*	Mayer-Oakes 1955b
Enos Holmes Mound	33HI6	S, *BC*	Church 1987
Felix	36WH85	*BC*	--
Feurt	33SC6	S, F, B, BC, *BC*	Mills 1917; Schurr and Schoeninger 1995; Wagner 1987
Finley (a.k.a. Old Finley Farm)	36WM18	S, *BC*	Mayer-Oakes 1955b

Table 13 (continued).

Name[1]	Number[1]	Data[2]	References[1]
Foster	33BU324	S, *BC*	Cowan, p.c.
Fox Farm	15MS1	S, F, B	Breitburg 1992; Rossen 1992; Smith 1910; Turnbow 1992
Francis	36FA15	S, *BC*	Mayer-Oakes 1955b; Swauger 1964
Fuller's Hill	36FA17	S, *BC*	Mayer-Oakes 1955b; Sciulli 1995
Gabriel	33AN6	S, F, B	Murphy 1975
Gartner	33RO19	S, F, B, BC	Mills 1904; Schurr and Schoeninger 1995; Wagner 1987
Globe Hill Shell Heap	46HK34-1	S, *BC*	Mayer-Oakes 1955a; Murphy 1977a
Gnagey	36SO55	S, F, B	Blake and Cutler 1983; George 1983a, 1983b; Hart and Scarry 1999
Godwin-Portman a.k.a. Goodwin-Portman a.k.a. Goodman-Portman	36AL39	S, *BC*	Hart 1995; Herbstritt 1988
Goolman	15CK146	S, F, B	Turnbow et al. 1983
Graham Village	33HO1	S, F, B	Cleland and Kearney 1967b; McKenzie 1967
Guard	12D29	S, *BC*	Cowan 1986; Sedler n.d.
Guilfoil	15FA167	S, F, B	Fassler 1987; Rossen 1987; Tune 1987
Hansen	15GP14	S, F, B	Ahler 1987, 1988; Breitburg 1988a; Lopinot 1988
Hardin Village	15GP22	S, BC	Broida 1983; Cassidy 1980; Hanson 1966
Hartley	36GR23	S, *BC*	Herbstritt 1988; Zimmerman and Randolph 1986
Hawkins Ridge	33HA182	S, *BC*	Cowan, p.c.; Genheimer, p.c.; Milner, p.c.
Haystack Rockshelters	15PO47A,B	S, B	Cowan 1978b, 1979a, 1997

Table 13 (continued).

Name[1]	Number[1]	Data[2]	References[1]
Henderson Mound #2	--	S, *BC*	Carskadden and Edmister 1992
Henderson Rocks	46TA1	S, F, BC	Baker 1976; Dragoo 1976a; Greenlee 1990; Tanner 1976
Hobson	33MS2	S, F, *BC*	Maslowski et al. 1995; Murphy 1968
Horseshoe Johnson	33BU204	S, *BC*	Cowan 1986
Household	36WM61	S, *BC*	George et al. 1990; Sciulli 1995
Howard Baum	33RO270	S, B	Carr and Haas 1996; Skinner 1992; Wagner 1987
Hughes Farm	46OH9	S, BC	Dunnell 1962; Farrow 1986
Incinerator	33MY57	S, F, B, BC	Conard 1988; Heilman et al. 1988; Schurr and Schoeninger 1995; Shane 1975, 1988; Wagner 1987, 1988b
Johnston	36IN2	S, F, *BC*	Dragoo 1955; George 1997; Guilday 1955; Sciulli 1995
Kelso a.k.a. Woodruff Farm	36WH23	S, *BC*	George 1995; Mayer-Oakes 1955b
Killen	33AD36	S, F, *BC*	Brose 1982; Brose et al. 1979; Storch 1979
King	36WM104	*BC*	--
Larkin	15BB13	S, BC	Pollack et al. 1987; Schurr 1998
Laughlin	15LW13	S, B	Henderson and Pollack 1992a; Rossen 1992
Leonard Haag a.k.a. Haag	12D19	S, F, B	Crawford 1981; Parmalee 1981; Reidhead 1980, 1981; Reidhead and Limp 1974
Madisonville	33HA14	S, F, B, *BC*	Cowan 1986; Drooker 1997; Dunavan 1993; Goodman et al. 1919; Hooton and Willoughby 1920
Man a.k.a. Mann	46LG5	S, BC	Brashler and Reed 1991; Moxley and Bloemker 1985

Table 13 (continued).

Name[1]	Number[1]	Data[2]	References[1]
McJunkin	36AL17	S, *BC*	George 1978a, 1997
McKees Rocks Village	36AL16	S, F, B, *BC*	Brose 1994; Buker 1968; Jones 1968; Lang 1968
Middle Site Island	36AL13	S, *BC*	Mayer-Oakes 1955b
Miller	46JA55	S, F	Murphy 1981; Wilkins 1981
Mon City	36WH737	S, F, B	Church 1994; Hart 1994
Montague	36SO4	S, *BC*	Butler 1939
Mount Carbon	46FA7	S, F	Guilday and Tanner 1965; Hemmings 1985; McMichael 1962
Muir	15JS86	S, F, B	Breitburg 1988b; Rossen 1988; Turnbow and Sharp 1988
Newtown Firehouse	33HA419	S, *BC*	Cowan, p.c.; Genheimer 1981
O.C. Voss Mound & Village	33FR52	S, *BC*	Baby et al. 1966, 1967; Carr and Haas 1996; Church 1987
Oglesby-Harris	33WA83	S, *BC*	Brose and White 1979, 1983
Ohioview	36BV9	S, *BC*	Alam 1960, 1961; Amockwi Chapter #17 1980; Citron 1967; Faingnaert and Doyle 1977; Mayer-Oakes 1955b
Peters Cave	--	S, F	Prufer and McKenzie 1966
Philo II	33MU76	S, F, B	Carskadden 1992; Carskadden and Morton 1977; Gartley et al. 1976; Maslowski et al. 1995; Morton 1977, 1989; Murphy 1977b, 1977c; Shane and Barber 1976
Pinnacle	36EL49	S, *BC*	Burkett 1977
Portman	36AL40	S, F, B, *BC*	Buker 1993
Proctor Rockshelter	46NI84	*BC*	Sciulli et al. 1993
Pyles	15MS28	S, F	Railey 1984
Raven Rocks	33BL52	S, F, B	Prufer 1981; Shane and Parmalee 1981

Table 13 (continued).

Name[1]	Number[1]	Data[2]	References[1]
Reservoir	36FA7	S, *BC*	Mayer-Oakes 1955b
Richards	33MU113	S, F, B	Carskadden and Morton 1977; Morton 1977; Murphy 1977b, 1977c
Riker	33TU02	S, F, *BC*	Barber 1974; Brose 1994; Prufer and Shane 1970
Rinehart	--	*BC*	--
Rochester	36BV80	S, *BC*	Alam 1957; Grumet 1995
Rogers Rockshelters	15PO26,27	S, B	Cowan 1979b
Roseberry Farm	46MS53	S, B, BC	Graybill 1979, 1981; Greenlee 1990; Wagner 1988c
Ryan	36WM23	S, F, B	George 1974, 1978b; Sciulli 1995
Saddle	46MR95	S, *BC*	Church 1995; Sciulli and Church 1995
Sand Ridge	33HA17	S, B, BC, *BC*	Riggs 1986; van der Merwe and Vogel 1978; Wagner 1987
Scarem	36WH22	S, F	Mayer-Oakes 1954
Schomaker	33HA400	S, F, B, *BC*	Cowan 1986; Cowan et al. 1990
Shippenport a.k.a. Shippingport	36BV4	S, *BC*	Guilday 1965; Mayer-Oakes 1955b
Slone	15PI11	S, F, BC, *BC*	Broida 1983; Dunnell 1972; Dunnell et al. 1971
Snag Creek	15BK2	S, F, B	Breitburg 1992; Pollack and Jobe 1992; Rossen 1992
Sony	36WM151	S, *BC*	Grumet 1995
State Line	33HA58	S, B, *BC*	Cowan 1986; Wheelersburg 1992
Thompson	15GP27	S, F, B	Breitburg 1992; Henderson and Pollack 1992b; Rossen 1992
Tower	15BL15	S, F	Brown 1981

Table 13 (continued).

Name[1]	Number[1]	Data[2]	References[1]
Turpin	33HA19	S, F, B, BC, *BC*	Riggs 1986; Theler and Harris 1988; van der Merwe and Vogel 1978; Wagner 1987
Ufferman	33DL12	S, *BC*	Barkes 1982; Dancy, p.c.
Varner	36GR1	S, F, *BC*	Guilday 1961; Mayer-Oakes 1955b; Sciulli 1995
Waterplant	33FR155	S, B	Carr and Haas 1996; Church 1987; Dancey 1988; Wymer 1987
Watson	33BU297	S, *BC*	Cowan, p.c.
White Rocks	33MO8	S, F	Ormerod 1983
Wise Rockshelter	33JA8	S, F	Oplinger 1981
Wood-73	33WA92	S, *BC*	Brose and White 1979, 1983
Woods	46MS14	S, B	Shott 1989, 1990a; Wymer 1990
W.S. Cole	33DL11	S, *BC*	Barkes 1982; Carr and Haas 1996; Church 1987
Wylie	36WH274	S, F	Eisert 1981; George 1995
Zencor a.k.a. Scioto Trails a.k.a. Merion Village	33FR8	S, B, *BC*	Carr and Haas 1996; Church 1987; Dancey 1988; Wymer 1987

[1] Missing data indicated by --.
[2] S = Site information (location, site type, settlement attributes); F = Faunal; B = Botanical; BC = Bone Chemistry, work of others; *BC* = Bone Chemistry, this research

While one might anticipate that this research history would make for straightforward comparisons across the study region, such is not the case. For example, assemblages of roughly the same age (e.g., A.D. 1200) may be identified as Late Prehistoric or Late Woodland in the literature, depending upon whether one is referring to central Ohio or southwest Pennsylvania locales, respectively. This confusion stems from attempts to link nonstylistic attributes, such as pottery temper, with time periods and the persistent confusion of "culture types" – an

anachronism of the Midwestern Taxonomic Method – and cultural "periods" (Dunnell 1986; Lyman et al. 1997). As a specific example, grit tempering is generally considered a characteristic of Late Woodland occupations. In the upper Ohio Valley, though, ceramic assemblages that belong to the Late Prehistoric period agewise often contain grit-tempered sherds and, consequently, are designated as Late Woodland assemblages. As a consequence, while units like "Late Woodland" are generally considered temporal periods, they are not always treated as such; this is exemplified by statements such as that by Barkes (1982:21) describing a set of archaeological locales as "Late Woodland sites culturally, but temporally contemporaneous with the Late Prehistoric Fort Ancient tradition."

The proliferation of units to partition geographical and temporal variation in the record makes chronological discussions that rely on them exceedingly complex. Figure 144 is a simplified chart, showing the major phases for a small sample of locales across the study area. A more comprehensive figure might include greater spatial detail (e.g., specific Ohio tributaries) and the schemes of more scholars. Indeed, considerable complexity is introduced as the number of researchers increases, because they have differing opinions on how phases should be defined, both geographically and temporally, and how they should be named (cf. Anderson 1991). Culture historical schemes for Late Woodland remains in the study area are slightly less complex, probably reflecting archaeologists' relatively recent interest in that part of the record.

The purpose for constructing such units merits consideration. Phases are designed to simplify spatial and temporal variation by deriving "average" descriptions that serve to represent that time and space (Dunnell 1971). To do so, the continua of time and space are arbitrarily divided into manageable chunks and variations in properties like settlement and subsistence are reduced to "typical" patterns, which then become the fodder for models and explanations of change. The goal of phase construction, then, is to minimize variation within each phase while

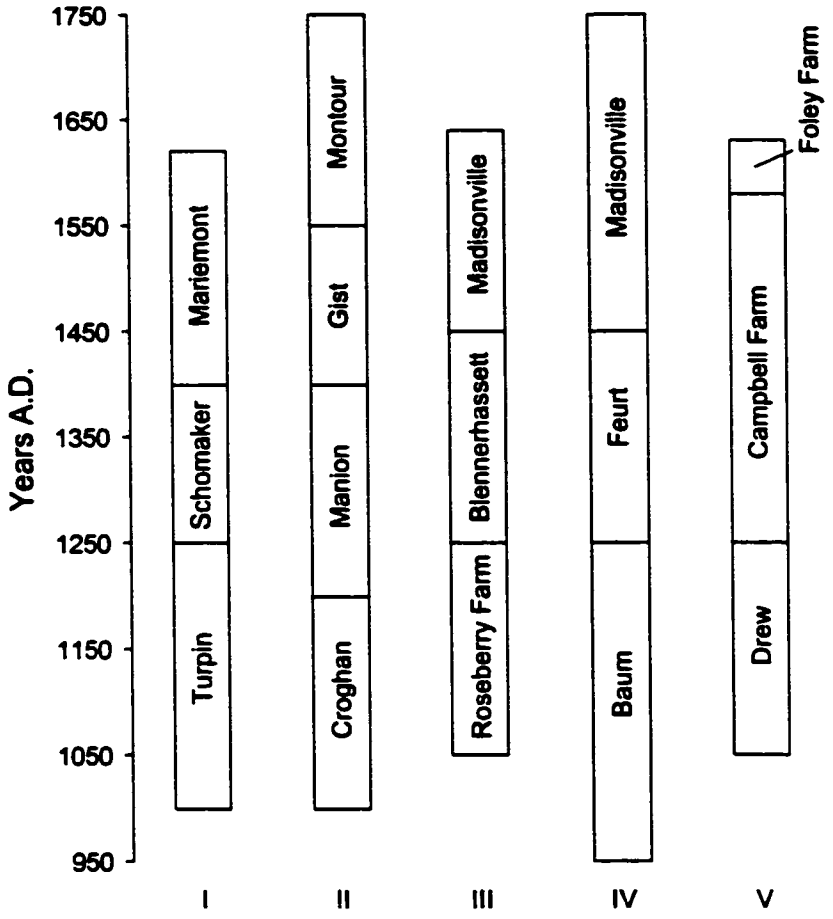


Figure 144. **Late Prehistoric culture historical phases in the study region.** Sequence I, southwest Ohio (Cowan 1986); II, central Kentucky (Henderson 1992); III, west-central West Virginia (Graybill 1986); IV, central Ohio (Prufer and Shane 1970); and V, southwest Pennsylvania (Hart 1993).

maximizing differences between phases. Given that the suppression of potentially meaningful variation is an inherent feature of units like phases, such culture historical units cannot provide an appropriate basis for the scientific examination of change through time.

In this research, time is treated as a continuous variable. When method or data deficiencies demand temporal classes, reference to local culture historical units is minimized. Instead, one broad temporal framework (Table 14) is applied across the entire study region. In so doing, I hope to avoid confusion that can stem from the complicated framework of culture historical sequences and to facilitate emphasis on spatial and temporal variation, as opposed to difference, in subsistence. As used here, these arbitrary units refer only to periods of time and carry no cultural connotations.

Table 14. Temporal periods used in this research.

Period	Age Range
Middle Woodland (MW)	A.D. 1 - A. D. 400
Late Woodland (LW)	A.D. 400 - A.D. 1000
Late Prehistoric (LP)	A. D. 1000 - A.D. 1650
early Late Prehistoric (eLP)	A.D. 1000 - A.D. 1250
middle Late Prehistoric (mLP)	A.D. 1250 - A.D. 1400
late Late Prehistoric (lLP)	A.D. 1400 - A.D. 1650

Problems in Chronology Construction

An examination of change through time requires good chronological control. Superficially, at least, this would appear not to be a problem here. In all, some 312 radiocarbon and 24 thermoluminescence (TL) determinations are available, to which I added ten more radiocarbon determinations.[74] Published descriptions of associated artifact assemblages are available for many deposits, as well. Yet, the task of establishing a useful chronological sequence is not at all straightforward. The difficulties can be traced to three main issues: (1) most of the deposits are palimpsests, (2) many radiometric dates rely on aggregate data, and (3)

[74] All determinations and statistical tests are presented at the end of this appendix.

chronometric determinations often have less precision than this archaeological problem requires. Here, I consider briefly the ramifications of these problems on establishing chronological control for this research.

Prehistorically, many locales were sites of repeat occupation. In the absence of significant sedimentary deposition between occupations, there was great potential for mixing the artifactual materials from one occupation with another. In such circumstances, it would require no effort for particles (e.g., wood charcoal, potsherds) from an earlier occupation to end up in the midden or features of a later occupation. In addition, those locales lacking significant sedimentation often remained at, or near, the ground surface, so modern agricultural activities and other processes of bioturbation might mix the entire deposit (or all but the deepest features) in the plowzone. The outcome of this situation is that it can be difficult to establish how many times a locale was occupied or to associate any particular artifact with any particular occupation.

Archaeologists usually select charred plant materials for radiocarbon determinations. Of the 206 radiocarbon determinations where the sample material is known, 143 (69%) were composed of charred wood, bark or "charcoal." Annually-produced plant materials like nutshell (charred, n = 7; uncharred, n = 5; unspecified n = 1), maize (n = 15), bean (n = 1) or grass (n = 1), and materials like bone [deer, n = 1; human = 29 (10 from this study); unidentified, n = 3] were less frequently used materials for radiocarbon determinations. Excepting the human bone samples, the relationships between the target and dated events are often poorly known, and this is particularly true for locales of multiple occupations. That this is a problem is well-attested in the literature, where "unacceptable" radiocarbon dates are often rejected because the age of the dated material does not fall within the expected age range based on other materials in that deposit. Of course, "aberrant" TL determinations often meet the same fate.

As a material, charcoal ranks highly in radiocarbon-date rating systems (e.g., Meltzer and Mead 1985). In this particular case, however, charred wood is probably one of the worst choices for establishing chronological control. Apparently ubiquitous, wood charcoal is easily moved about, and it has no characteristics that would allow archaeologists to determine to which occupation it truly belongs. This problem is compounded when radiocarbon determinations are made using an aggregate of charcoal fragments culled from one or more depositional units. This is a frequent strategy for meeting the sample size requirements of conventional, as opposed to AMS, dates. Because the resulting date reflects a weighted average age of all of the pieces, for locales of multiple occupations, this strategy can produce meaningless dates. Aggregate mixing of charcoal from different occupations could easily produce an apparently continuous occupation of a locale as indicated in the radiocarbon record in contrast to archaeological evidence for multiple temporally-discrete occupations. Unfortunately, the practice of dating aggregates, as opposed to individual chunks, of charcoal is seldom specifically documented in publications so it is difficult to determine when such has occurred.

Thermoluminescence dates have been acquired for burned stone (n = 21), pottery (n = 2) and burned clay (n = 1). A TL date reflects the last heating event of a material sample, which could be the date of its manufacture, its last use, or a post-depositional event (Feathers 1997). Because these (except perhaps the lattermost) are cultural events, TL dates may be more relevant to archaeological questions regarding occupation age than other dating techniques. In other words, with thermoluminescence, there is a close link between dated and target events. At locales where multiple occupations have occurred, multiple heated artifacts may be TL dated to assess the number and sequence of occupations and individual artifacts can be tied to particular occupations. The age of human skeletal remains or particular subsistence remains, which may be variably related to the occupational history of a locale, must be established based on association arguments.

For dietary studies, radiometrically-dated human skeletal remains can resolve some of these problems. The dated and target events are clearly related – they are the same for all intents and purposes. Information about diet, time of death (and life), age at death, sex, development and disease history are all easily integrated at the scale of the individual organism. If the timing and sequence of occupational episodes at a locale is known, the individuals can be related to particular occupations. Alternatively, it may be that the disposition of individuals at a locale is unrelated to the occupation of that place. In the absence of temporally-sensitive grave goods, directly dating skeletal remains may be the only, and is clearly the preferable, way to establish how they relate to the occupational history of the locale.

The imprecision associated with radiometric dates provides an additional source of complexity in untangling the occupational histories of these locales (cf. Shott 1992). Imprecision refers to both sample measurement error and, for radiocarbon dates, past fluctuations in atmospheric radiocarbon that, in combination, are reflected in the age range associated with any particular determination. Here, the 2σ age range for calibrated radiocarbon determinations is from 104 to 1316 calendar years (mean $\pm$ 2 sd = 323 $\pm$ 333 years), typically a large-enough range to make using the calibration curve intercepts as "mean" age estimates useful only in establishing basic patterns of temporal variation. When detailed comparisons among assemblages are required, consideration of the age ranges involved becomes critical. Because the 2σ age range can be so large, in some cases, the timing of different occupations will not be distinguishable, even when archaeological evidence indicates they were temporally discrete events.

Because of these issues, radiometric estimates of the occupational history of a locale can provide outcomes of varying utility. Thus, an independent dating strategy, like seriation, can serve as a check of the relative ordering of the dated deposits and it can allow locales without radiometric dates to be incorporated

into the developed chronology. However, the seriation method is hampered by the palimpsest nature of these deposits, as well. To be successful, seriations require artifact assemblages that result from discrete occupational episodes. Those assemblages that do reflect discrete occupations are usually from single use locales, which are often well-dated radiometrically; artifact assemblages from locales of multiple occupations are rarely separated on the basis of the different occupations which produced them. Consequently, those cases which would most benefit from seriation are those cases where it is least likely to be successful.

These issues are certainly relevant to this research, documenting subsistence and dietary variation through time and across space. Below, I describe my attempts to establish chronological control by evaluating the published record of radiometric dates, including ten radiocarbon determinations obtained by me during the course of this research, and by supplementing those data with information on temporally-sensitive artifact attributes when necessary and possible. Because of the great number of deposits involved, particular emphasis is placed on establishing local chronological sequences and my results are compared with published sequences to the extent possible.

ESTABLISHING CHRONOLOGICAL CONTROL

As noted above, the radiocarbon determinations relevant to this research total 322 dates (312 are previously published and 10 are newly obtained). These determinations are spread unevenly across 88 of the 125 locales considered here; some locales have been dated as many as twenty times, others only once. A similar situation exists for the thermoluminescence dates. The 24 TL determinations are spread across eight locales, all in Kentucky and all but one having radiocarbon dates, as well; some locales have as many as five TL dates, others only one.

For each locale, the reported radiocarbon ages were calibrated and the resulting intercepts and the 1σ and 2σ age ranges (in calendar years B.C./A.D.) were plotted. When multiple radiocarbon dates were available for a locale, apparent clusters of samples were tested via χ^2 to establish that they were consistent with a single sample population (Ward and Wilson 1978) and that outliers and/or other clusters were indeed from statistically different populations. Different clusters at a locale are believed to reflect different use episodes there. These results were compared with archaeological evidence of the occupational history at each locale. To resolve apparent conflicts, I turned to a consideration of the material dated, when available, and other sources of information that might bear on the problem (e.g., excavation strategy, artifact classification).

Finally, I combined the data from each locale to obtain local sequences that place the dated occupations in each river system[75] in chronological order. Figure 145 shows how the sample was divided to produce the local sequences. Once these sequences were established, seriations and/or artifact assemblage comparisons were used to incorporate undated deposits into the temporal schemes. Finally, summary tables that place each occupation into its appropriate time period are produced. Each of these sequences is presented below.

Sequence I: Main Trench, Ohio River, Eastern Section

The available radiocarbon determinations for locales from this geographic area are shown in Figure 146. Both Globe Hill Shell Heap and Ohioview had radiocarbon ages which were significantly older than the time period of primary interest here. Although a multicomponent deposit, Globe Hill Shell Heap saw its

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[75] The locales that comprise these sequences are united primarily on the basis of geography, not evidence for cultural interaction or historical relatedness. The latter would be the best way to approach the problem, but data quality prohibits such an assessment; a geographic approach is thus more inclusive.

primary occupation during the Late Archaic period (Murphy 1977a). The human skeletal material analyzed from there is probably from a Middle or Late Woodland occupation (Sciulli p.c.).[76] Ohioview also experienced multiple occupations; the available radiocarbon determination reflects an occupation during the Early

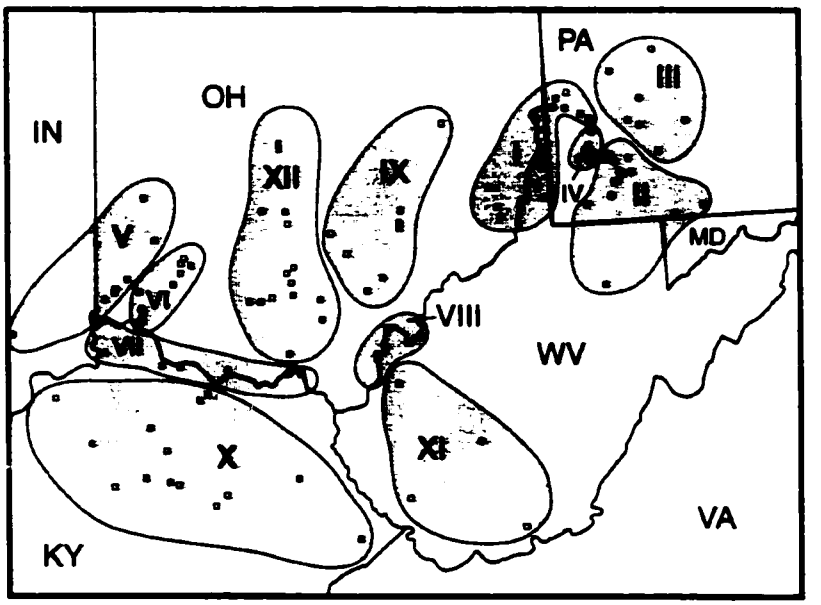


Figure 145. **Allocation of sites into local sequences.** □ symbols indicate the locations of assemblages listed in Table 13. See Figures 142 and 143 for site identifications.

Woodland period, but there were significant Late Prehistoric occupations, as well (Alam 1961; Faingnaert and Doyle 1977). The ceramic assemblage found there includes types found throughout the Late Prehistoric period (Figure 147), but the bulk may be associated with an early Late Prehistoric occupation. Although Sciulli (p.c.) indicated the human skeletal material analyzed here is from the Late Woodland period, published data on artifacts found with several burials (of

[76] Time periods for Upper Valley sites were provided upon completion of isotopic analyses by Sciulli without justification; for some, I have no independent information to either support or refute such assignments.

unknown relationship to the two analyzed here) indicate a Late Prehistoric affiliation (Alam 1961).

The occupational histories of the two rockshelters in this sample of locales, Raven Rocks and White Rocks, are similar to many rockshelters in the study area. Although material remains of several time periods are present, the artifact assemblages are dominated by materials from the Late Woodland period. Thus, the lone radiocarbon dates, while not documenting the temporal range of

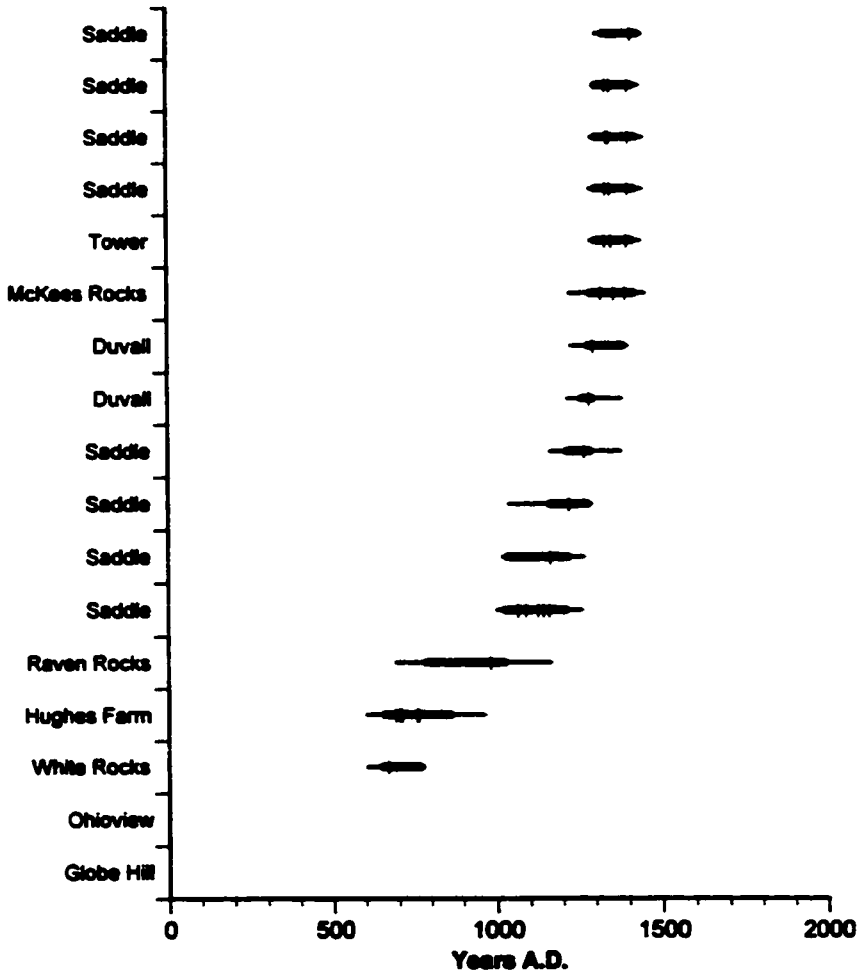


Figure 146. **Calendrical ages for Sequence I, the eastern section of the main trench of the Ohio River.** Vertical bars indicate intercepts; thick bars reflect the 1σ range and thin bars, the 2σ range.

occupations that occurred at these locales, are consistent with the predominant time of their use (Ormerod 1983; Prufer 1981). White Rocks provides a rare case wherein artifacts have been separated on stratigraphic grounds into assemblages assumed to be roughly associated with different occupations (Ormerod 1983); both the Late Woodland and (undated, but probably) early Late Prehistoric materials are of relevance here.

	Half-Moon Ware	Mahoning Ware	Watson Ware	Monongahela Ware	Scarem Plain
Rochester/ McKees Rocks				x	
Duvall/Scarem/Britt				x	x
Middle Site Island/ Hughes Farm		x	x	x	x
Ohioview	x	x	x	x	x
Shippenport	x	x	x	x	

Figure 147. **Relative chronological ordering of locales in Sequence I.** Ordering based on presence of different ceramic wares.

The Hughes Farm radiometric date appears to reflect a Late Woodland occupation at that stratified, multicomponent locale. Its Late Prehistoric artifact assemblage, however, is dominated by materials that compare nicely with others that are early Late Prehistoric in age (Dunnell 1962) and the skeletal materials were found in early Late Prehistoric contexts. Similarly, multiple occupations are documented at Duvall; the radiocarbon determination and the bulk of artifacts are consistent with a primary occupation during the middle Late Prehistoric period (Dunnell 1980a).

The radiometric determinations from Tower, McKees Rocks and Saddle appear to be consistent with archaeological evidence. That the radiocarbon record indicates two occupations at Saddle, one during the early and one during the middle Late Prehistoric periods, is also supported by the excavation record, and

importantly for this research, the burials have been identified accordingly (Church 1995; Sciulli and Church 1995). The radiocarbon record and ceramic assemblage both attest to a middle Late Prehistoric occupation at McKees Rocks Village (believed to be a cultural intrusion into the region), although a large later one has been documented there as well.

It is interesting that the radiometrically-determined ages of the sampled deposits in this area do not extend beyond about A.D. 1450. Following the work of Johnson, however, Grumet (1995) has identified three of the locales from this geographic area as having had post-A.D. 1600 occupations (Rochester, McKees Rocks and Hughes Farm). Those age estimates are based on the presence of objects believed to be of European origin and/or objects elsewhere associated with very late occupations. Recent analyses of copper artifacts from Hughes Farm have demonstrated that the copper is a native, not European, material (Dunnell and Greenlee 1999); however, the recovery of red glass beads associated with extended burials suggests there may be a Protohistoric component at or near the Hughes Farm locale (Johnson 1998).

A simple occurrence seriation of different ceramic wares (Figure 147) was used to incorporate undated deposits into this local sequence. The classification used (Mayer-Oakes 1955b) reflects primarily tempering material and it does not always seriate successfully when applied over the upper Ohio Valley; however, the order produced here appears to be consonant with the radiocarbon record and with other researchers' assessments of the relative age of at least some of these deposits (e.g., Grumet 1995; Hart 1993). Even though the ceramic seriation suggests an early Late Prehistoric occupation at Shippenport, Sciulli (p.c.) indicated that the skeletal materials date to the late Late Prehistoric period, ca. A.D. 1400 – 1500.

To this point, only three locales from this geographic area have not been considered, 46OH13, 46OH1 and 46BR2. A seriation of rim styles by Dunnell (1962) placed 46OH13 chronologically after Hughes Farm and before Britt Bottom;

Farrow (1986) later argued that the best sequence places 46OH13 chronologically earlier than Hughes Farm. Either way, that occupation probably dates to the early Late Prehistoric period. No chronological information, except that they are both Late Prehistoric in age (Mayer-Oakes 1955b), is available for either 46OH1 or 46BR2.

Table 15 integrates these data by placing the occupations into their most appropriate time period (as defined in Table 14). In addition to the radiometric dates and seriation, information gleaned from site reports was used in this assessment. Certainly some placements are more secure than others. For locales with multiple occupations, each occupation is listed, with poorly-documented and/or minor ones in italics. Major occupations at a locale are presented in regular font.

Table 15. Summary of occupational history for Sequence I, the eastern section of the main trench of the Ohio River.

Late Woodland	early Late Prehistoric	middle Late Prehistoric	late Late Prehistoric
White Rocks	Shippenport	Scarem	*McKees Rocks*
Hughes Farm	Ohioview	Britt Bottom	Rochester
Raven Rocks	Hughes Farm	Duvall	*Shippenport*
	Middle Site Island	*Hughes Farm*	*Hughes Farm*
	46OH13	McKees Rocks	
	Saddle	Tower	
	White Rocks	Saddle	

Sequence II: The Monongahela and Youghiogheny River Systems

The radiocarbon-dated occupations of the Monongahela and Youghiogheny River area are shown in Figure 148. Importantly, for four locales (Bunola, Fuller's Hill, Household and Varner), dates were obtained using human skeletal material; bone chemistry data are generated here for individuals from those

locales. Of the locales with multiple determinations, dates and artifacts for four of them are consistent with single occupations (Bunola, Henderson Rocks, Household and Mon City).

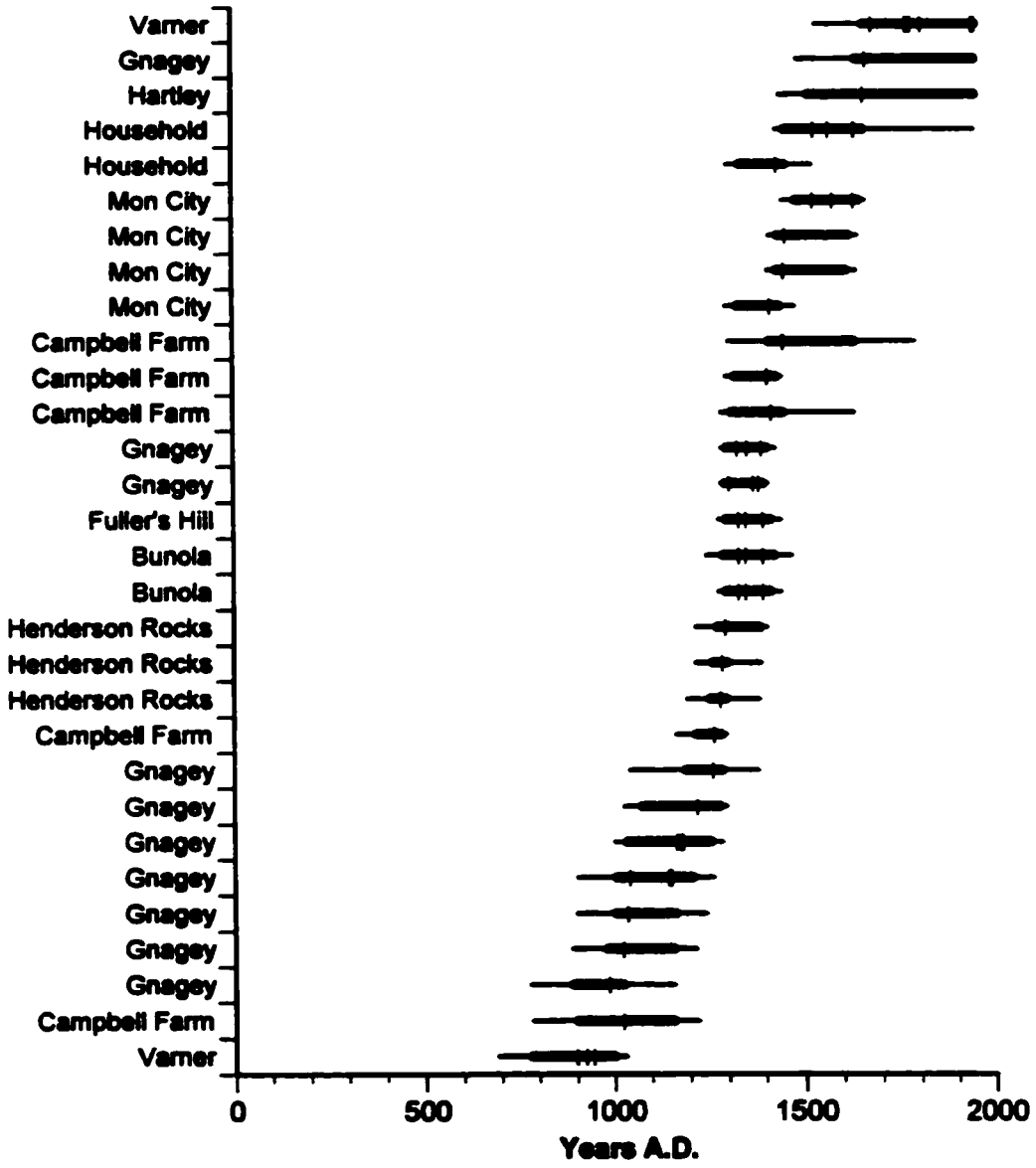


Figure 148. **Calendrical ages for Sequence II, the Monongahela and Youghiogheny Rivers.**

Visual examination and statistical testing of the radiocarbon record indicate that a few of the locales are multicomponent and this is generally supported by evidence from excavation. The radiocarbon and excavation records from Campbell Farm are both best accounted for by three occupations, with the major occupation occuring during the middle Late Prehistoric period. Varner is the only clearly Late Woodland/early Late Prehistoric occupation and it apparently has a minor Protohistoric/Historic component, as well (Grumet 1995; Johnson 1998).

The dates from Gnagey are consistent with two prehistoric occupations and a historic use of the locale. Although archaeological evidence indicates two prehistoric villages, the dates cannot distinguish them (i.e., the earliest date apparently comes from the stockade trench of the later village; the only date from a feature associated with the earlier village occurs midway in the sequence). Although George (1983b) identified the earliest occupation at Gnagey as Late Woodland, calibrated dates and artifactual materials indicate that it actually occurred during the early Late Prehistoric period; radiocarbon dates seem to indicate that the second village was occupied then, too. Hart and Scarry (1999) presented two ^{14}C dates on beans that correspond to the middle Late Prehistoric period, but the context of those materials was not reported. Finally, one date that came from a small pit containing Euroamerican materials is clearly historic in age.

Many locales in the area are undated and seriation will be required to fit them into this scheme. Seriations of the materials from this geographic area are more complicated than along the main trench of the Ohio River. Whereas temper appears to discriminate adequately along temporal lines further west, it is less informative here. In some areas, shell tempering (like that in Monongahela ware) remains rare, even in assemblages that "should" be dominated by it. The grit-tempered Somerset ware (George 1983b) is temporally equivalent to the shell-tempered Monongahela ware; Somerset cannot be differentiated from Watson ware (a grit-tempered ware that is usually associated with Late Woodland assemblages)

here because they are not distinguished consistently in the literature. Thus, the best approach would be to produce seriations based on some other classification. Unfortunately, for several locales, the composition of the ceramic assemblage is the only information available by which to establish the relative age of their occupations. Surprisingly enough, however, the arrangement produced by the occurrence seriation in Figure 149 is roughly consistent with radiometric and other data regarding the age of these occupations. The ordering is consistent with other published schemes which apparently rely on other characteristics (Hart 1993; Johnson 1998).

	Watson/Somerset Ware	Monongahela Ware	Scarem Plain
Fuller's Hill/Francis		x	
Household/Finley		x	x
Bunola/Henderson Rocks	x	x	x
Montague/Varner	x	x	

Figure 149. **Relative chronological ordering of locales in Sequence II.** Ordering based on presence of different ceramic wares.

Additional information comes from Grumet (1995), who, on the basis of Euroamerican artifacts, identified four locales (Household, Hartley, Fuller's Hill, and Sony) as having post-A.D. 1600 components. Only two locales, Elliot and Reservoir, lack data by which they could be integrated into the temporal sequence for this geographic area. Both are identified as being Late Prehistoric in age (Mayer-Oakes 1955b; Sciulli, p.c.). Sciulli (p.c.) indicates the burials are from Late Prehistoric occupations. Table 16 integrates all of these sources of chronological information for the geographic area, again placing each occupation into its appropriate temporal period. The number of Late Woodland occupations is considerably smaller and the number of late (post-A.D. 1400) occupations is noticeably greater in this area of the study region than elsewhere in the upper Ohio River valley. The latter has been observed before (e.g., Grumet 1995).

Table 16. Summary of occupational history for Sequence II, the Monongahela and Youghiogheny Rivers.

Late Woodland	early Late Prehistoric	middle Late Prehistoric	late Late Prehistoric
Varner	Montague	Campbell Farm	Mon City
	Gnagey	Henderson Rocks	Household
	Campbell Farm	Bunola	Finley
	Varner	Fuller's Hill	*Gnagey*
		Francis	Hartley
			Fuller's Hill
			Sony

Sequence III: The Allegheny, Beaver and Connemaugh River Systems

The radiocarbon sequence for this geographic area is shown in Figure 150. The radiocarbon record from Ryan is particularly enigmatic. It appears to indicate two different populations of samples, one Late Woodland in age, the other early Late Prehistoric. Reports by George (1974, 1978b) indicate a single, short-term early Late Prehistoric occupation there. The ceramic assemblage includes a single sherd stylistically Early Woodland and the lithics span a long history, from the PaleoIndian period through the Late Prehistoric. In rejecting the two early dates, George (1974) noted that the samples were composed of several scattered fragments of charcoal; those two Late Woodland determinations may be statistical averages of two populations, one from the Late Prehistoric occupation and the other much earlier. Consequently, they were excluded from further consideration. The remaining two dates, one on human bone, are consistent with an early Late Prehistoric occupation there.

The radiocarbon determinations that indicate two occupations at Bonnie Brook and three at McJunkin also appear to be consonant with the archaeological records at those locales (George 1997; Herbstritt 1981). Both occupations at Bonnie Brook occurred during the late Late Prehistoric period. The

middle Late Prehistoric occupation at McJunkin is believed to be the predominant one there.

Radiocarbon dates are available for all but two of the locales considered from this geographic area (Pinnacle and "36AR?"). Pinnacle is an undated rockshelter deposit located in Elk County, PA (Burkett 1977), in the

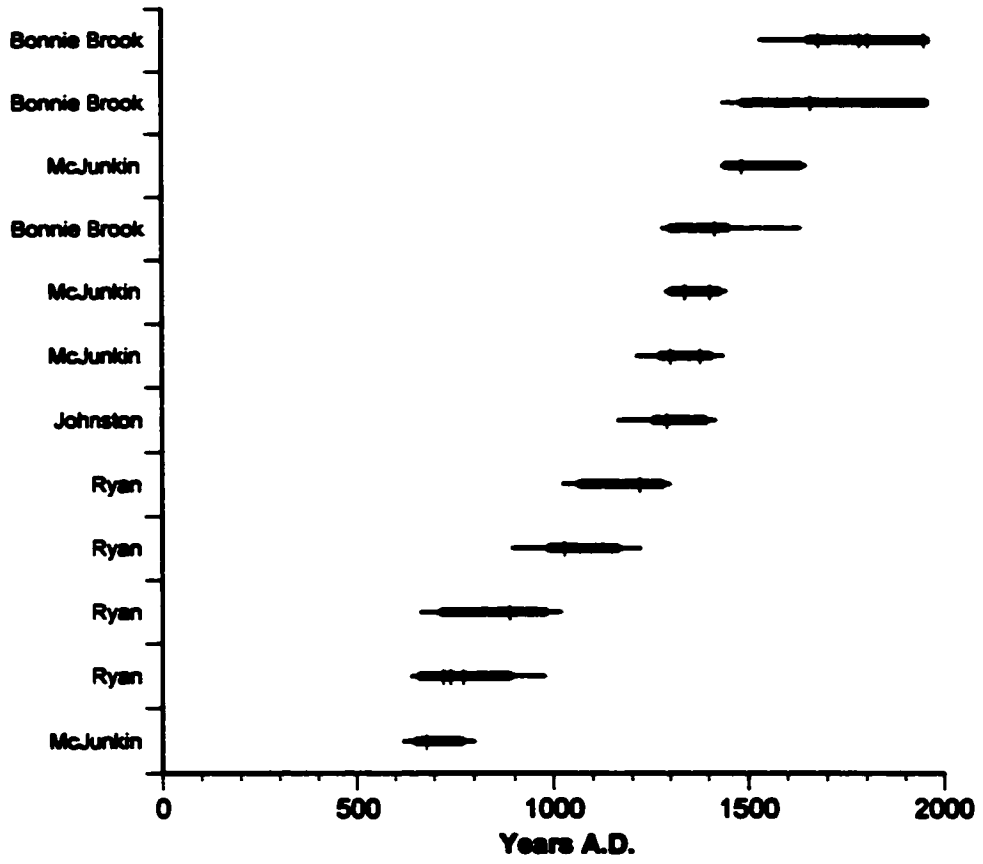


Figure 150. **Calendrical ages for Sequence III, the Allegheny, Beaver and Conemaugh Rivers.**

extreme northeastern portion of the study region. Included with a burial in the rockshelter was a pot, decorated with herringbone incisions, similar to others in New York dated to roughly A.D. 1310. The locale vaguely identified as "36AR?" was

identified as a Late Woodland deposit by Sciulli (p.c.). The entire sequence is summarized in Table 17.

Table 17. Summary of occupational history for Sequence III, the Allegheny, Beaver and Conemaugh Rivers.

Late Woodland	early Late Prehistoric	middle Late Prehistoric	late Late Prehistoric
McJunkin	Ryan	Johnston	*McJunkin*
"36AR?"		McJunkin	Bonnie Brook
		Pinnacle	

Sequence IV: The Chartiers Creek System

The radiocarbon record for occupations along Chartiers Creek is shown in Figure 151. There is surprisingly little spread. Indeed, excepting the early occupation at Portman, one would be hard-pressed to identify any of the occupations as definitely later or earlier than any of the others. Portman is the only locale in the area with two occupations indicated by the radiocarbon record; this is consistent with archaeological evidence (Buker 1993). The skeletal materials analyzed are believed to be associated with the middle Late Prehistoric occupation there (Sciulli, p.c.). The only locale which lacks radiometric dates is Ashmore Farm, identified by Sciulli (p.c.) as Late Prehistoric in age.

An occurrence seriation, based again on temper type, provides equivocal results. Ashmore Farm could fit on either the top or bottom of two solutions; the solution which is in best agreement with the radiocarbon sequence (Figure 152) makes less sense in terms of the temporal sequence of ceramic wares than the solution which conflicts with the radiocarbon sequence (Figure 153). Factors which probably contribute to this situation are the short time span involved relative to the coarseness of the ware classes, the "slop" resulting from the seriation's reliance on a classification with a strong technological/functional

component, and the presence of materials from earlier occupations. No matter which solution is chosen, Ashmore Farm could be the earliest or latest occupation in the series. The ceramic assemblage from Ashmore Farm is quite small (n = 308),

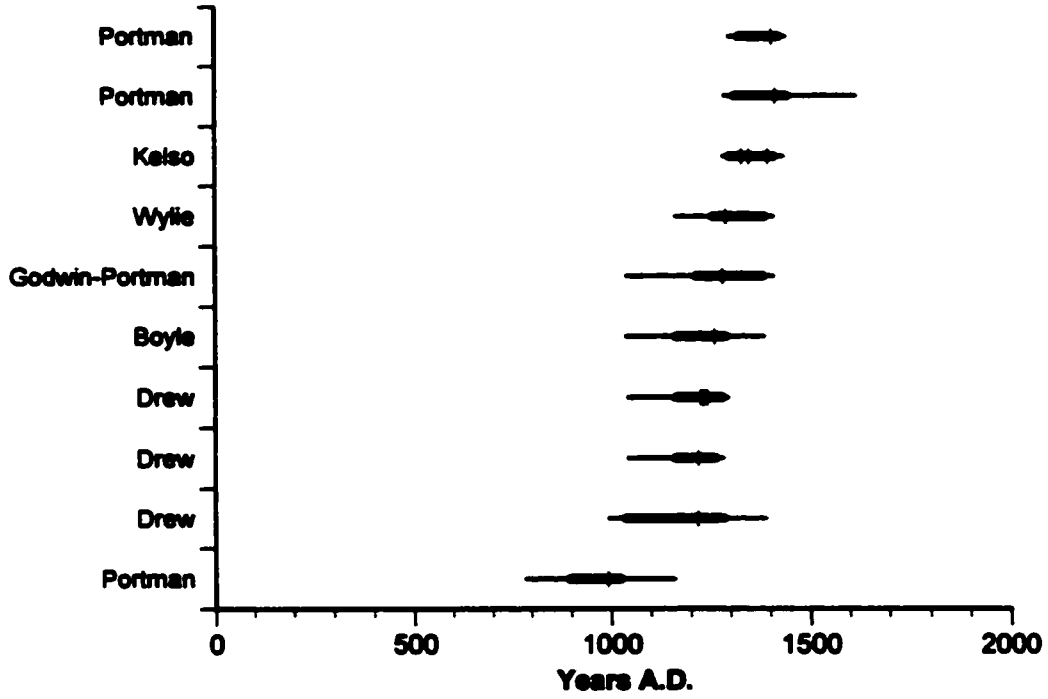


Figure 151. **Calendrical ages for Sequence IV, Chartiers Creek.**

	Mahoning Ware	Watson Ware	Monongahela Ware	Scarem Plain
Ashmore Farm?		x	x	
Wylie	x	x	x	
Boyle	x	x	x	x
Drew/Portman		x	x	x
Ashmore Farm?		x	x	

Figure 152. **One relative chronological ordering of locales in Sequence IV.** Ordering based on presence of different ceramic wares. This solution is in best agreement with the radiocarbon record.

	Mahoning Ware	Watson Ware	Monongahela Ware	Scarem Plain
Ashmore Farm?		x	x	
Drew/Portman		x	x	x
Boyle	x	x	x	x
Wylie	x	x	x	
Ashmore Farm?		x	x	

Figure 153. **A second relative chronological ordering of locales in Sequence IV.** This solution is in best agreement with the sequence of ceramic wares in the region.

and so sample size could have decreased the potential of acquiring sherds from minor wares. Overall, the artifacts from Ashmore Farm appear closely similar to other Chartiers Creek locales like Wylie, Boyle and Drew (Eisert and Boyce 1985). There is no evidence for a late Late Prehistoric occupation at any of these Chartiers Creek locales. Table 18 presents a summary of the occupational history for this suite of locales.

Table 18. Summary of occupational history for Sequence IV, Chartiers Creek.

Late Woodland	early Late Prehistoric	middle Late Prehistoric	late Late Prehistoric
Portman	Drew	Godwin-Portman	
	Boyle	Wylie	
	Ashmore Farm?	Kelso	
		Portman	
		Ashmore Farm?	

Other Upper Ohio River Valley Materials

There are four Upper Valley locales for which I was not able to determine location beyond state and county. Skeletal materials from these locales were identified as to the relevant time period: A.M. Byers is Late Woodland and Barn, Felix and King are Late Prehistoric in age (Sciulli, p.c.).

Sequence V: The Great Miami River System

Figure 154 shows the radiocarbon record for locales along the Great Miami River. For simplicity's sake, I have included one locale, the C. L. Lewis Stone Mound, amongst those of the Great Miami River area even though it really is a geographic (and temporal) outlier. One radiocarbon date obtained by me from human skeletal material from the mound was Early Woodland in age; this date is slightly earlier than, but in the same ballpark as, a previously reported age of 80 B.C. (Kellar 1983). The skeletal materials are significantly older than the time period of interest. Radiocarbon determinations from Guard and Campbell Island are consistent with archaeological evidence for single occupations at those locales during the early and late Late Prehistoric periods, respectively. Although the dates from State Line are statistically consistent with a single occupation, archaeologists (e.g., Cowan 1986) consider State Line as having had at least two significant Late Prehistoric occupations.

The radiocarbon chronology from Leonard Haag is rather messy. That there has been significant mixing of materials is illustrated by a charred grass mat, recovered from the bottom of a Late Prehistoric storage pit, that provided a Middle Woodland date (Reidhead 1981; Reidhead and Limp 1974). The radiocarbon determinations form three clusters, both visually and statistically, dating to the Middle Woodland, Late Woodland, and middle Late Prehistoric periods. Although the Middle Woodland dates are considered by many to be unrelated to the Late Woodland occupation at Leonard Haag, similar occupations at other locales in the region with similar materials (e.g., Turpin, Hansen, Sand Ridge) have produced similar determinations. I am concerned here with the Late Woodland and middle Late Prehistoric occupations at Haag and, importantly, the faunal and botanical assemblages have been subdivided accordingly.

Visually, there is considerable overlap among the radiocarbon dates from Schomaker; statistically, they indicate two sample populations. While there

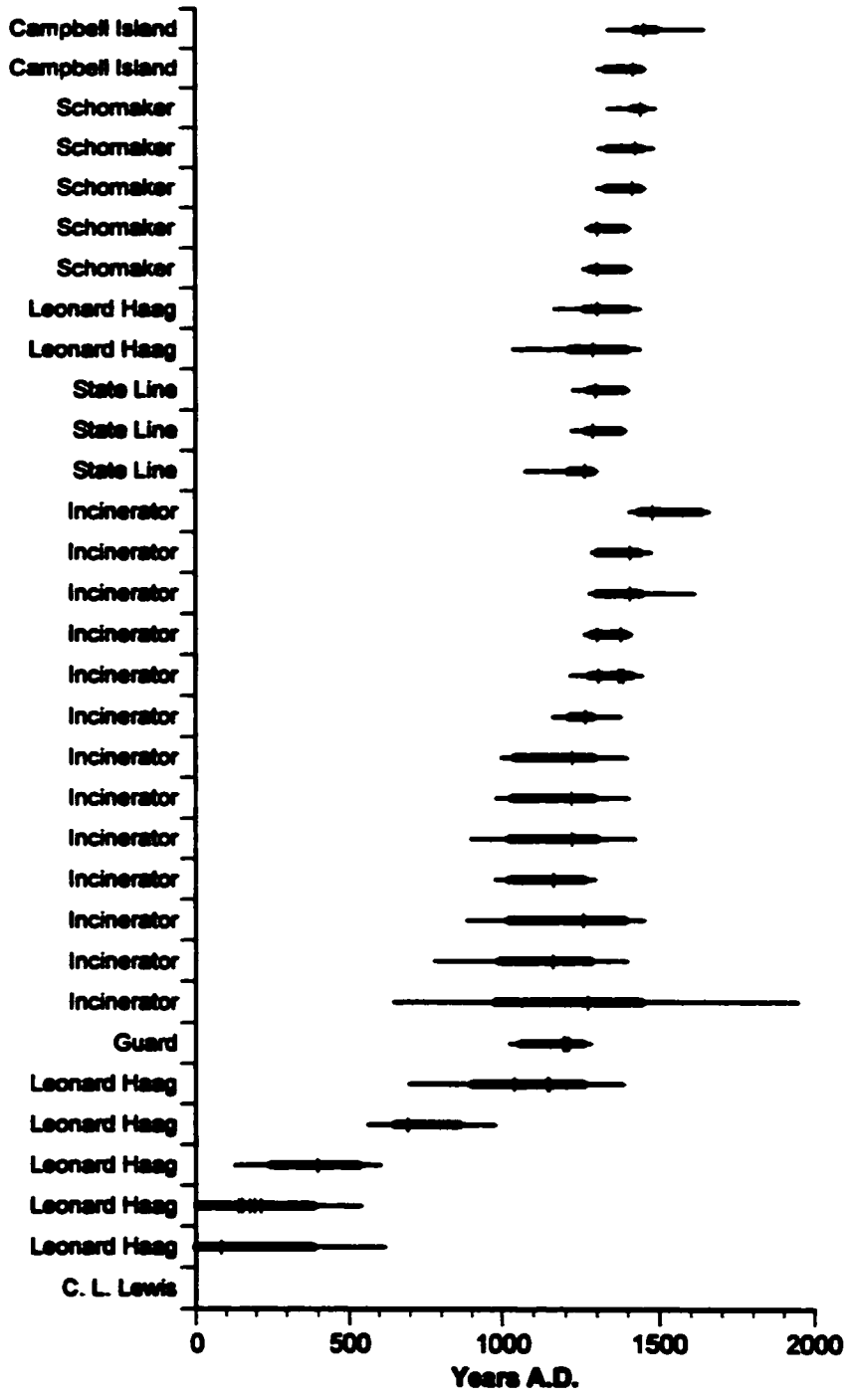


Figure 154. Calendrical ages for Sequence V, the Great Miami River area.

are several ways one could group these dates and not reject the null hypothesis (of no difference), grouping together the earliest two and the latest three makes the greatest sense, both statistically (before calibration) and visually (after calibration). This solution is consistent with excavational evidence for two distinct occupations at this locale (Cowan et al. 1990). One occupation appears to be middle Late Prehistoric in age and the other occurred early in the late Late Prehistoric period.

The sequence of dates from Incinerator spans the early, middle and late Prehistoric periods, yet archaeological evidence would seem to suggest a single occupation of relatively short duration, with little rebuilding. Statistical analysis of the dates indicates that, with the removal of the most recent determination, the samples represent a single population. Consistent with this, I note that there is a significant overlap in the 2σ age ranges for 11 of the remaining twelve samples between about A.D. 1250 - 1350; the twelfth overlaps that time frame slightly. The artifact assemblage from Incinerator is closely similar to that of Schomaker (Cowan et al. 1990), suggesting that the bulk of the occupation probably occurred during the middle Late Prehistoric period. In light of these observations and without data about the composition and context of the outlying recent sample, it was excluded from further consideration.

Only two locales from this geographic area lack radiocarbon determinations, Watson and Foster. Both are Late Prehistoric in age, and Watson most likely belongs to the early Late Prehistoric period (Cowan 1986; Cowan p.c.). Table 19 periodizes occupational history of locales from the area around the Great Miami River.

Sequence VI: The Little Miami River System

All of the locales in this geographic area have radiocarbon determinations, shown in Figure 155. Carroll-Oregonia Road, Horseshoe Johnson, Hawkins Ridge and Anderson all have single dates. In the cases of Carroll-

Table 19. Summary of occupational history for Sequence V, the Great Miami River area.

Late Woodland	early Late Prehistoric	middle Late Prehistoric	late Late Prehistoric
Leonard Haag	Guard	Incinerator	Campbell Island
	State Line	State Line	*Schomaker*
	Leonard Haag	Leonard Haag	
	Incinerator	Schomaker	
	Watson		

Oregonia Road and Horseshoe Johnson, the dates appear to reflect well the occupational history at these locales (Brose and White 1983; Cowan 1986), but at Anderson, the date reflects only one of several occupations there (Essenpreis 1982). The bulk of the materials at Anderson appear to have been deposited during the middle Late Prehistoric period. The radiocarbon date from Hawkins Ridge, a small stone mound, is from charcoal obtained just beneath the deposit of skeletal materials.

Two locales with two relevant radiocarbon dates, Oglesby-Harris and Wood-73, were both sites of multiple occupation. For Oglesby-Harris, the bulk of the diagnostic artifactual materials (and one radiocarbon date not considered here) was Archaic in age; charcoal was dated to the Late Woodland period, while human bone from a burial there dated to the early Late Prehistoric period (Brose and White 1983). At Wood-73, there was evidence (both artifactual and radiocarbon) for occupations during the Archaic and Early/Middle Woodland periods, but Brose and White (1983) identified several features as probably reflecting use during the Late Woodland and Late Prehistoric periods. Charcoal from two of those features provided Late Woodland and early Late Prehistoric dates. A Late Prehistoric Madison point was found with one of the burials and, thus, that burial is assumed to be associated with the early Late Prehistoric occupation. Although Bunnell Kame was identified as a multiple-use Late Prehistoric mortuary facility

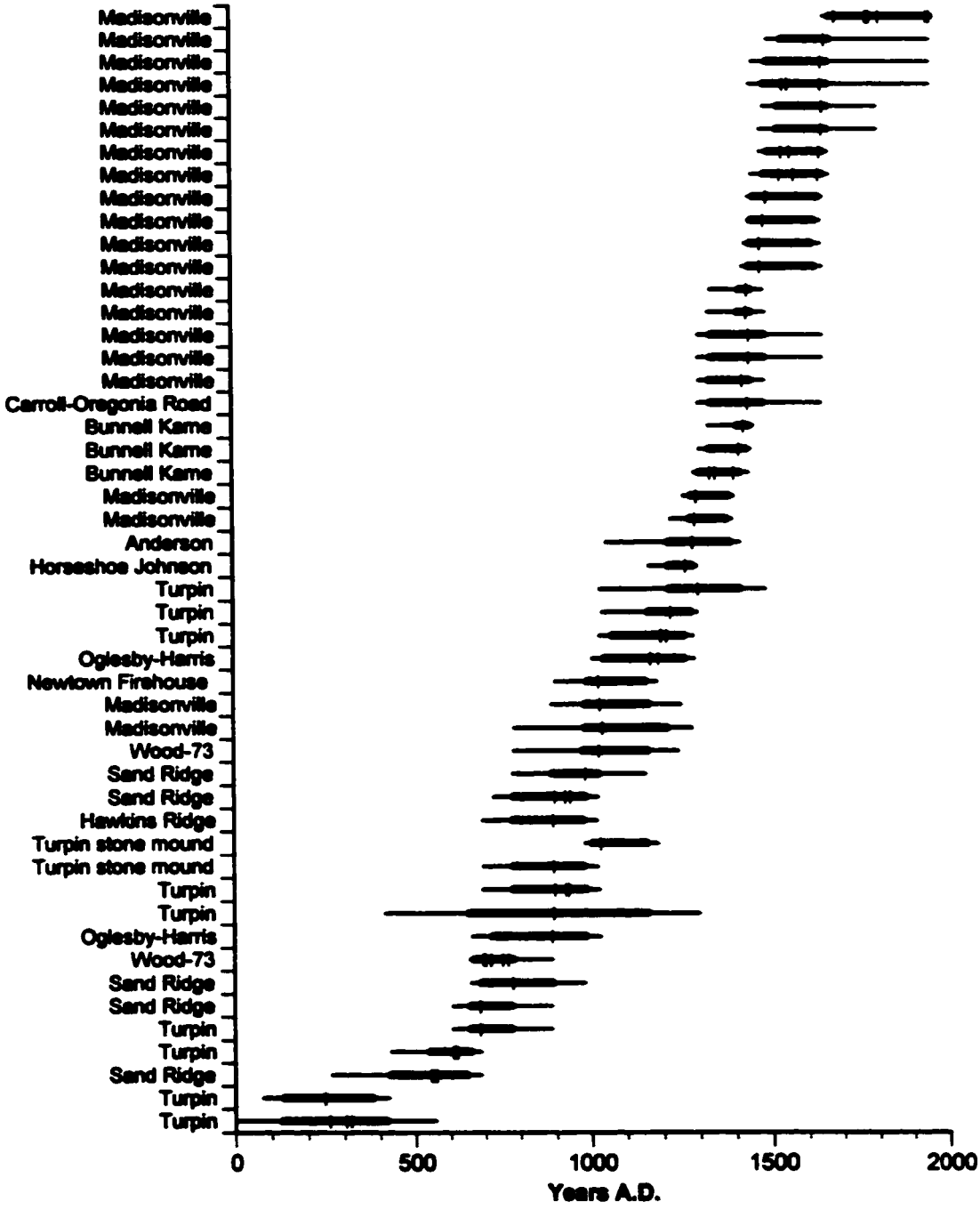


Figure 155. **Calendrical ages for Sequence VI, the Little Miami River area.**

(Brose and White 1983), the three radiocarbon determinations are consistent with a single statistical population.

The radiocarbon records for locales with several dates are much more complex. Depending on how samples are grouped for analysis, Sand Ridge has three clusters, Turpin has four, and Madisonville has five. Although Sand Ridge clearly has a significant Late Prehistoric component, the radiocarbon dates in Figure 155 reflect exclusively Late Woodland contexts. Comparisons of the artifact assemblages with other dated assemblages in the area suggest that the Late Prehistoric component probably belongs to the middle Late Prehistoric period (Cowan 1986; Drooker 1997; Riggs 1986).

The radiocarbon sequence from Turpin is consistent with four occupations at that locale. Like the earliest dates at Leonard Haag, the earliest two dates from Turpin, which are on charcoal associated with classic Newtown ceramics, are often rejected as being too early. Although the excavations did not reveal any intact Middle Woodland deposits, apparently cultural materials from that time period have been recovered from the site. Two clusters of dates are Late Woodland in age and the last belongs to the early Late Prehistoric period. Two of the radiocarbon determinations from Turpin are newly-acquired analyses of skeletal materials from the stone mound. These dates represent the latest of the Late Woodland determinations (statistically, the latest Late Woodland bone date could be grouped with the early Late Prehistoric dates). Finally, Cowan (1986) noted the presence at Turpin of a small number of ceramics with attributes characteristic of those found at late Late Prehistoric locales.

Until recently, Madisonville has been treated as a late Late Prehistoric phenomenon. However, detailed research by Drooker (1997) has conclusively demonstrated that the complex archaeological record at Madisonville was created by multiple occupations over a long time span. Using both radiocarbon determinations and artifact assemblages, she identified at least four separate

occupations there, dating to the early, middle and late Late Prehistoric periods. In Table 20, I periodize the occupational history of locales in the vicinity of the Little Miami River.

Table 20. Summary of occupational history for Sequence VI, the Little Miami River area.

Late Woodland	early Late Prehistoric	middle Late Prehistoric	late Late Prehistoric
Sand Ridge	Wood-73	Horseshoe Johnson	Madisonville
Turpin	*Madisonville*	Anderson	*Turpin*
Wood-73	Newtown Firehouse	Madisonville	*Anderson*
Oglesby-Harris	Oglesby-Harris	Bunnell Kame	Carroll-Oregonia Road
Hawkins Ridge	Turpin	Sand Ridge	

Sequence VII: Main Trench, Ohio River, Western Section:

In Figure 156, I show the radiocarbon record for locales along the western portion of the main trench of the Ohio River. This represents all but two locales, Hardin and Laughlin, from that geographic area. Both Hardin and Laughlin have significant amounts of Euroamerican materials in their artifact assemblages and thus have been identified as late Late Prehistoric period occupations (Hanson 1966; Henderson and Pollack 1992a). Hardin apparently had a middle Late Prehistoric occupation and Laughlin apparently had an early historic (Euroamerican) occupation, as well.

The four radiocarbon dates from the Killen locale are statistically consistent with a single population. The archaeological evidence, which suggests a single occupation during the middle Late Prehistoric period, is in agreement with this conclusion (Brose 1982). The relevant radiocarbon record from Hansen indicates two statistical populations, one from the Middle Woodland period and one later, from the Late Woodland period. Ahler (1987) indicated the archaeological evidence is consistent with this, with a single occupation during the late Middle

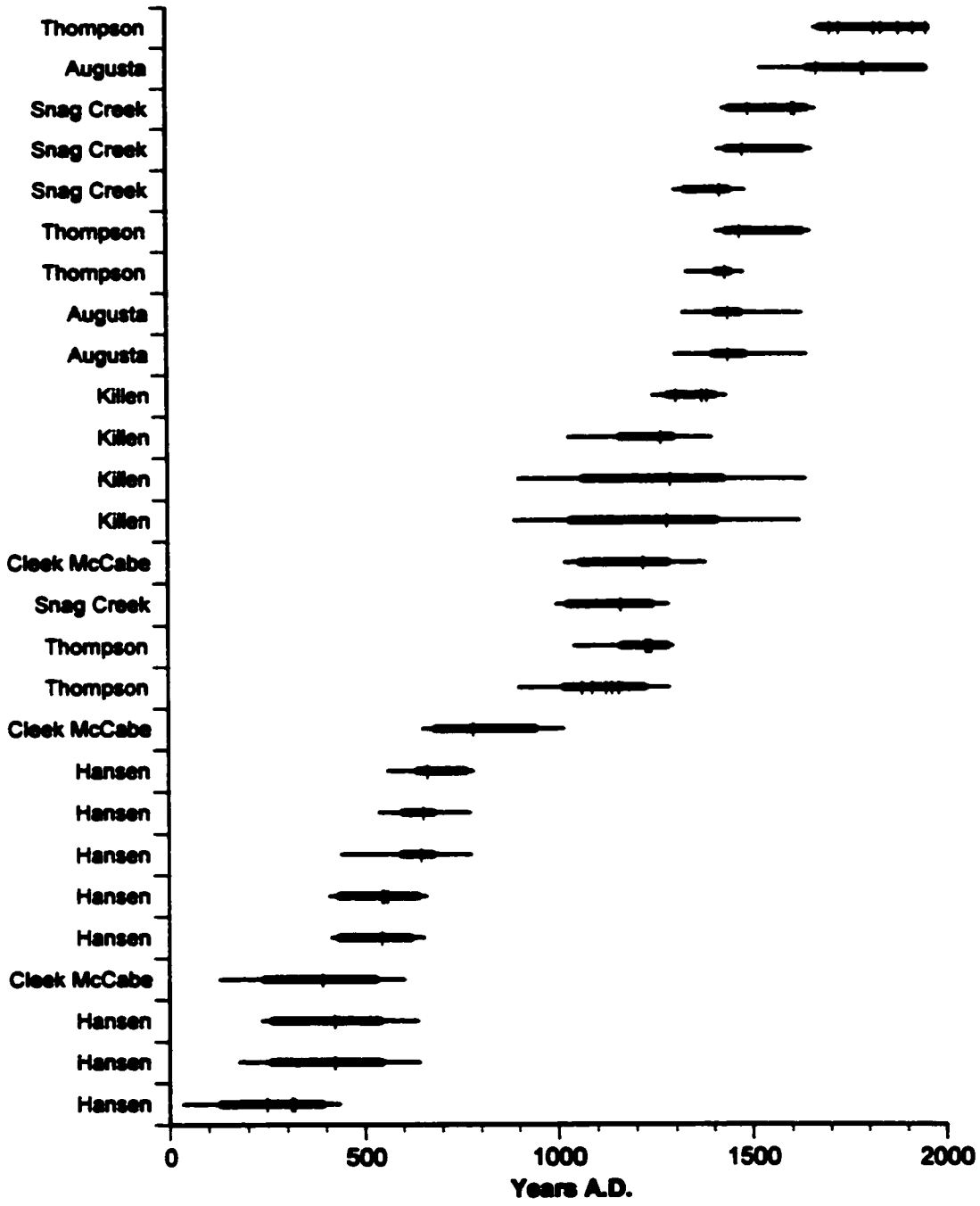


Figure 156. **Calendrical ages for Sequence VII, the main trench of the Ohio River, western section.**

Woodland period and another during the early Late Woodland, but there actually may have been two temporally-distinct Late Woodland occupations there.

Of the locales with multiple dates, Cleek-McCabe has the greatest spreads between each determination. For Cleek-McCabe, all of the determinations are on human skeletal material, with two samples (the earliest two) from below the burial mound and a third from below the associated village midden (Rafferty 1974); thus, they represent maximum ages. The burial mound was maximally a Middle Woodland construction, while the village was occupied both concurrently and later. The bones, in poor condition and coated with preservative, did not provide an undoubtedly reliable material for dating. Multiple independent seriations apparently confirm the temporal position of Cleek-McCabe as an early Late Prehistoric occupation (Rafferty 1974).

Other locales with multiple clusters of dates (Augusta, Snag Creek and Thompson) also have excavational and artifactual evidence for multiple occupations (Henderson 1992) that appear to correspond chronologically to the dates. Several, but not all, TL dates from Thompson support the radiocarbon determinations from that locale. Table 21 summarizes the chronological sequence for the western section of the main trench of the Ohio River.

Table 21. Summary of occupational history for Sequence VII, the western section of the main trench of the Ohio River.

Late Woodland	early Late Prehistoric	middle Late Prehistoric	late Late Prehistoric
Hansen	Thompson	Killen	Augusta
Cleek-McCabe	Cleek-McCabe	*Hardin*	Snag Creek
Snag Creek	*Snag Creek*		*Thompson*
			Hardin
			Laughlin

Sequence VIII: Main Trench, Ohio River, Middle Section

Figure 157 shows the local radiocarbon chronology for this area. The bulk of dates (94%) are from three locales (Woods, Childers and Roseberry Farm).

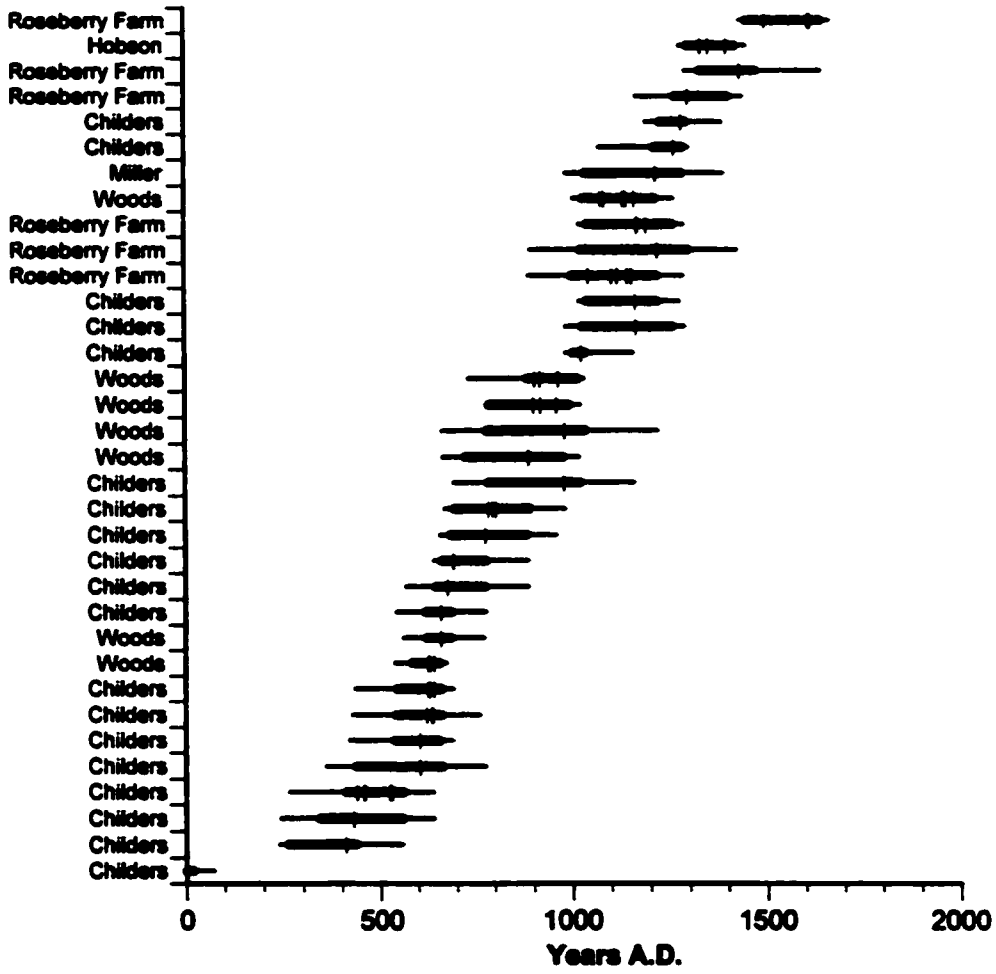


Figure 157. **Calendrical ages for Sequence VIII, the middle section of the main trench of the Ohio River.**

The seven radiocarbon determinations from the Woods locale appear to reflect at least two, and perhaps three, distinct occupations there. There is archaeological evidence for two occupations during the Late Woodland period, the first being rather minor and the second, later, one being somewhat more substantial (Shott 1990a). A third, still later, occupation is suggested by one or possibly two

radiocarbon determinations, although archaeological evidence for that episode is apparently lacking.

Despite having, or alternatively because there are, twenty radiocarbon determinations on materials from Childers, establishing the occupational history at that locale is extremely problematic (Shott 1989, 1990a, 1992). In particular, the radiocarbon determinations indicate one long continuous occupation or perhaps a series of discrete occupations, whereas archaeological evidence would seem to suggest a single short-term occupation. Shott (1992) presented a detailed consideration of the radiocarbon determinations, considering factors such as sample provenience and material, interlaboratory variation, and the probabilistic nature of radiocarbon dating. He concluded that most of the determinations should be disregarded and argues strongly for a single, short occupation (Figure 158a), the best age estimate of which is roughly A.D. 585 (Shott 1992). I have no reason to disagree with his well-reasoned conclusions regarding the occupational history at Childers. Determinations based on the human skeletal remains should not have been excluded simply because the material was bone, however.

Prior to this research, two of the Childers radiocarbon determinations were on human bone. Those dates (UGa-5597 and DIC-1496) have been regarded as questionable because they don't agree with other accepted dates, nor do they appear to agree with each other (Figure 158b). I acquired one more, a high precision, conventional radiocarbon age on a previously unanalyzed burial from Childers (Feature 24 [Marwitt et al. 1986]); QL-4932 dated to 995 ± 34 ^{14}C years B.P., with a δ^{13}C value of -13.51 ‰. QL-4932 is plotted in Figures 158b and 158c.

One of the previously-dated samples, UGa-5597, with a date of 1092 ± 93 ^{14}C years B.P. (Maslowski p.c.; Shott 1992) appears to overlap considerably with my QL-4932 determination (Figure 158b). UGa-5597 was a conventional date (i.e., it was corrected for sample fractionation; the δ^{13}C on the dated material was -24.88

‰). The second previously-dated bone sample, DIC-1496, was dated to 750 ± 55 ^{14}C years B.P. (Maslowski and Dawson 1980) and was not corrected for fractionation (Maslowski, p.c.). Because some of the members of the Childers community were maize-consumers, fractionation may have a significant impact on the calibrated date. Using the $\delta^{13}C$ values of collagen from the two dated samples, UGa-5597 and QL-4932, I determined minimum and maximum fractionation effects on DIC-1496 and calibrated both accordingly; they are both plotted in Figure 158c.

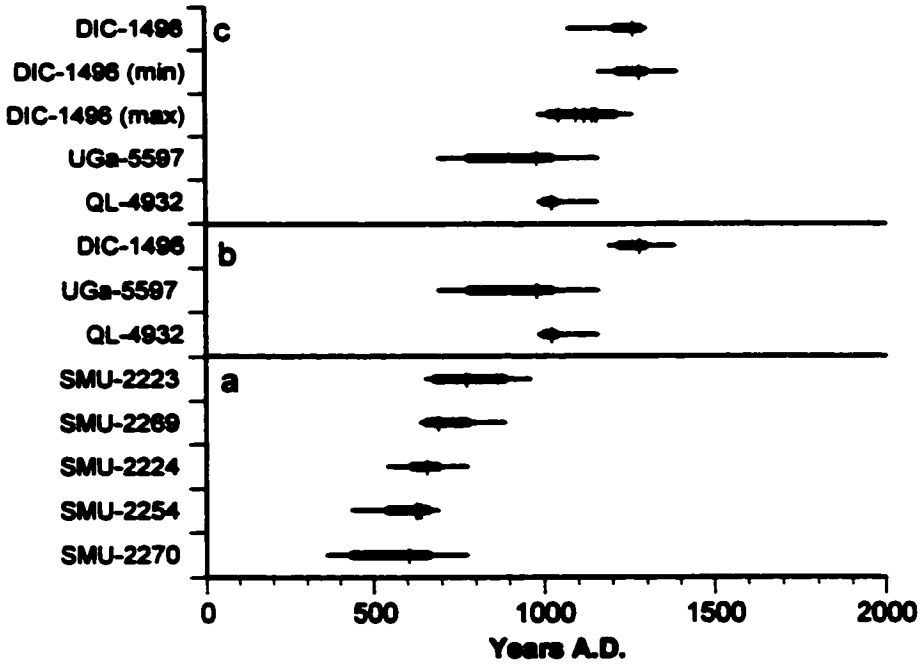


Figure 158. **Detailed consideration of the Childers ^{14}C dates.** (a) the suite of SMU- dates not rejected by Shott (1992); (b) dates on human bone as reported, with DIC-1496 uncorrected for fractionation; (c) bone dates with a maximum isotopic correction for DIC-1496, a minimum correction for DIC-1496, and including DIC-1498, a previously unrejected, but not accepted, date.

Initial consideration of the three bone dates as shown in Figure 158b leads one to conclude that the burials were probably deposited at different times, all later than the occupation as delimited by Shott (1992), or because they are later

than expected and are quite variable, one might be tempted to disregard them as being contaminated to greater or lesser degrees with more recent humic substances. Depending upon how DIC-1496 is corrected for the effects of isotopic fractionation, the results may be more consistent (Figure 158c). If DIC-1496 was enriched (requiring the maximum correction), all three of these burials at Childers were deposited more or less contemporaneously, but about 500 - 600 years later than the occupation. If DIC-1496 was depleted (requiring the minimum correction), then that burial does not coincide statistically with the other two burials; interestingly, though, the age of that burial would overlap a single nonbone radiocarbon date (DIC-1498) that was not rejected due to questionable provenience or other criteria, but is not fully accepted either (Shott 1992). Those more recent ages would correspond to what may be the most recent in the series of occupations at the nearby Woods locale.

Superficially, determining which scenario is correct would seem to be as straightforward as obtaining a $\delta^{13}C$ value from the individual who supplied the DIC-1496 sample. It will not be that simple. This individual, like the "Bankcut" burial dated as UGa-5597, was found eroding from the riverbank. In the case of UGa-5597, the $\delta^{13}C$ value of the collagen fraction by the dating laboratory (Maslowski p.c.) was -20.38 ‰[77]; I analyzed another bone identified as belonging to the same individual and it had a $\delta^{13}C$ value of -13.25 ± 0.04 ‰. Obviously, the "Bankcut" burial was composed of more than one individual. The same could be true of the burial dated as DIC-1496. To adequately resolve the age of the burials at Childers will require more radiocarbon dates, taking care to ensure that they are corrected for isotopic fractionation. For now, I assume that the human burials are associated with a later use of the locale.

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[77] This $\delta^{13}C$ estimate differs slightly from the one used to correct the ^{14}C date because sample processing for dating purposes is somewhat different than for dietary analysis.

The radiocarbon chronology from Roseberry Farm is also difficult to square with other archaeological evidence, which suggests minor Middle and Late Woodland deposits underlying an early Late Prehistoric village (Graybill 1979, 1981). Apparently, each of three samples (two charcoal, one bone) were split and sent to two different laboratories for radiocarbon dating. The results are somewhat ambiguous (Figure 159a), but there are several unknowns not addressed in the literature.

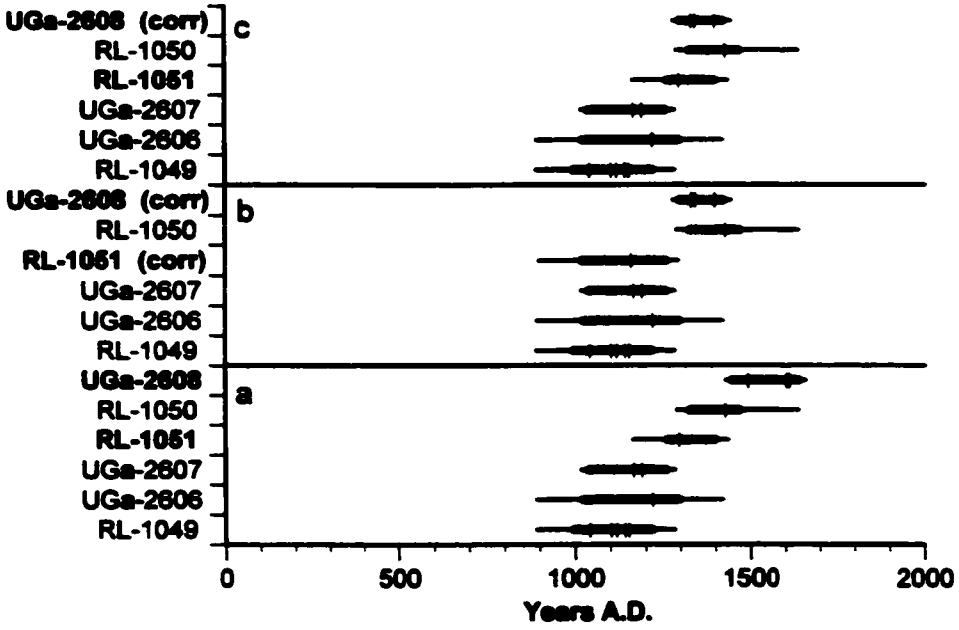


Figure 159. **Detailed consideration of radiocarbon determinations from Roseberry Farm.** (a) all samples, bone uncorrected for fractionation; (b) all samples, bone corrected for fractionation; (c) all samples, UGa-2608 only corrected for fractionation. Bone samples are in boldface.

For example, were the initial charcoal samples two large pieces that were subsequently split or were they aggregates of charcoal that were each divided into two portions? If the charcoal samples were aggregates, differences between the two laboratories for one sample but not for the other could be easily explained. That the apparently late charcoal date (RL-1050) does not match its mate (UGa-2606)

could reflect its composition, i.e., the two samples contained charcoal fragments of different ages. Perhaps RL-1050 contained charcoal from a minor, undocumented later occupation or even of historic origin.

Was the bone human or animal? If the bone was human, it may not have been corrected for isotopic fractionation. Since subsequent isotopic analysis of human skeletal remains revealed that inhabitants there were isotopically enriched (Greenlee 1990), this could explain why the bone dates tend to be younger than most of the charcoal dates. Correction of the two bone dates for isotopic fractionation would change the radiocarbon record to two clusters, an early cluster of four dates and a later one of two dates (Figure 159b). This does not account for the large separation between the two bone dates, however. Reportedly, one of the bone samples was considered barely adequate and, if it were so small as to affect the radiocarbon estimate, that could explain the difference between them. It was not reported which of the two bone samples may have been too small.

Although error due to sample size is one way to account for the differing ages produced by the different laboratories, an equally plausible solution is that one determination (RL-1051) may have been corrected for fractionation, but the other (UGa-2608) was not. With correction of the latter (using the mean, -11.08 ‰, of five previously measured $\delta^{13}C$ values of individuals from Roseberry Farm [Greenlee 1990]), the two ages overlap and are statistically from the same population (Figure 159c). They also concur with the latest charcoal date (RL-1050), and suggest two uses of the Roseberry locale. In that case, the burials would be from an episode of use later than the primary occupation, dating roughly to the mid-1300s; although this would be a fairly late use of mounds for mortuary purposes in the region, there are other known cases (e.g., Bunnell Kame). This scenario is unlikely, however, because UGa dates are typically corrected for fractionation.

Admittedly, the scenarios posed to resolve the Roseberry Farm and, to a lesser extent, the Childers radiocarbon chronologies involve some speculation that may not be accurate. They should be considered hypotheses that could be easily tested with future work. These examples highlight two important observations: (1) that it is critical to make certain when dating bone (particularly human bone), that the radiocarbon age is corrected for fractionation, and to clearly state whether the age is conventional or not; and (2) that human remains need not be associated with the major occupations at a locale, and consequently they should be dated independently. Until more data are obtained, I (1) regard the burials at Childers as having been interred during a later use of the locale than the primary occupation there, and (2) ignore the two bone and one aberrant charcoal dates, thereby assuming that a single occupation at Roseberry Farm indeed occurred during the early Late Prehistoric period.

I turn now to information provided by seriations on the order of three other Late Prehistoric occupations (Hobson, Roseberry Farm and Miller) sampled in this area; this discussion is based on the work of Graybill (1981). Using multiple seriations (including triangular projectile point base form and ceramic surface treatment), Graybill found that the assemblages from Hobson seriate earlier than the radiocarbon date indicates. In the seriations, Hobson is consistently ordered with Roseberry Farm, mainly an early Late Prehistoric-aged occupation, yet the single radiocarbon determination apparently dates later, to the middle Late Prehistoric period. Murphy (1968) noted that, in comparison to other similar sites, the artifact assemblage at Hobson indicated its major occupation dated to roughly A.D. 1100 – 1200. Thus, Hobson was an early Late Prehistoric occupation, but with evidence for other occupations, both earlier and later, present. Apparently, the radiocarbon sample was associated with a minor later occupation there.

In Table 22, I summarize the local occupational history for this area. Here, perhaps more than elsewhere, there is ambiguity as to the age of the

occupations, and even simply identifying the relevant time periods represented is more challenging than for other areas.

Table 22. Summary of occupational history for Sequence VIII, the middle section of the main trench of the Ohio River.

Late Woodland	early Late Prehistoric	middle Late Prehistoric	late Late Prehistoric
Childers	Childers	*Hobson*	
Woods	*Woods*	*Roseberry Farm?*	
	Roseberry Farm		
	Miller		
	Hobson		

Sequence IX: Muskingum and Hocking River Systems

The radiocarbon chronology for occupations in the vicinity of the Muskingum and Hocking Rivers is shown in Figure 160. Only two locales, Peters Cave and Wise Rockshelter, are undated. The cultural materials from shelter B at Peters Cave were identified as belonging solely to the Late Woodland period (Prufer and McKenzie 1966). Wise Rockshelter contains artifacts from a broad time span, but comparison with assemblages from other dated occupations indicates that, like many rockshelters in the study region, the bulk of materials were deposited during the Late Woodland period (Oplinger 1981). The same can be said for Chesser Cave, i.e., cultural materials were predominantly deposited during the Late Woodland, even though the lone radiocarbon determination from there falls in the early Late Prehistoric time period (Prufer 1967). The two radiocarbon determinations from Henderson Mound #2 (one obtained here using human bone) are in close agreement that it is a Late Woodland deposit (Carskadden and Edmister 1992).

Superficially, the two dates from Graham Village appear to reflect distinct occupations. However, since both determinations have large error terms, a χ^2 test indicates that they are statistically from the same population and thus, could

reflect the same occupation. McKenzie (1967) noted, though, that the sample with the late date was obtained from a hearth partially disturbed by plowing and thus was probably contaminated by historic materials. A single occupation during the late Late Woodland or early Late Prehistoric periods is consistent with archaeological evidence provided by McKenzie (1967), however Murphy (1975) indicates there was a middle Late Prehistoric occupation there, as well.

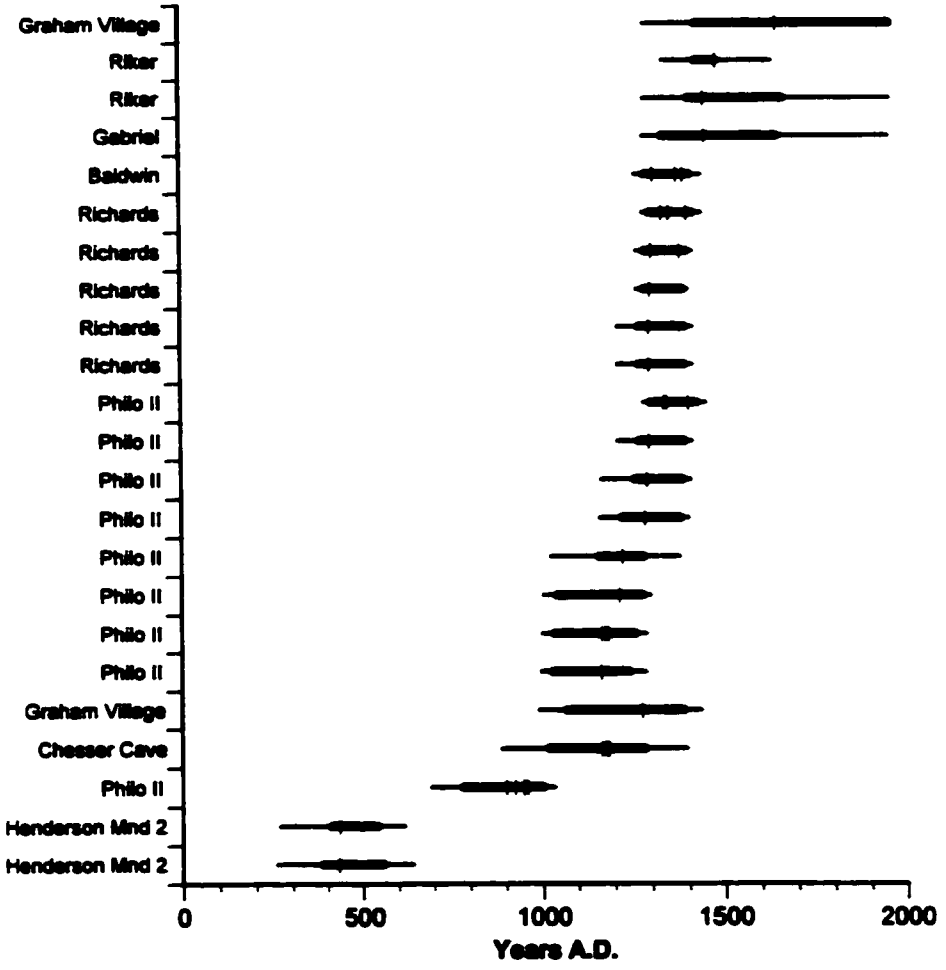


Figure 160. **Calendrical ages for Sequence IX, the Hocking and Muskingum Rivers.**

In the surface treatment of its ceramic assemblage, Graham appears to seriate with the Late Woodland rockshelter occupations (Figure 161), although

the distribution of base forms among its triangular points (Figure 162) would seem to suggest that Graham is more closely allied with the early Late Prehistoric occupations. Given that the rockshelters probably represent special-purpose hunting camps and Graham is a habitation site, that Graham seriates differently from them may reflect a functional aspect of the projectile point base form classification.

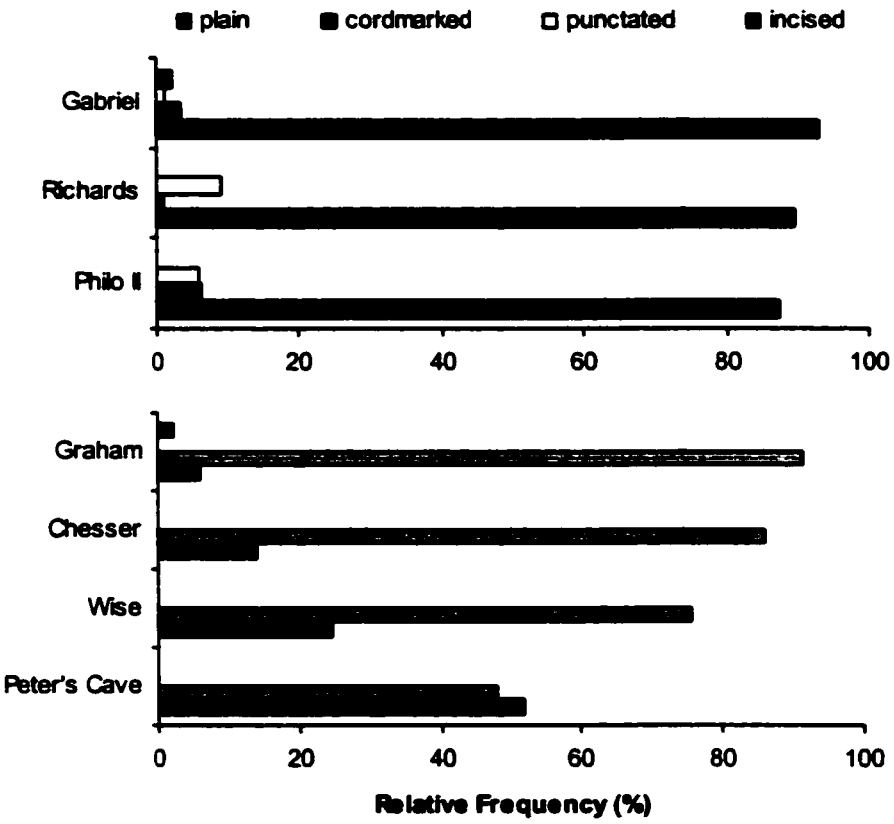


Figure 161. **Relative frequencies of ceramic surface treatments.**

There is a minor Late Woodland component at Philo II and this is indicated by the single early date. Three other radiocarbon samples from contexts believed to be Late Woodland in age based on associated artifacts were found to be more recent (Morton 1989), suggesting perhaps some mixing of feature contents. In total, eight determinations from Philo II fall within the early and middle Late

Prehistoric periods. Visually, that distribution might reflect either two distinct Late Prehistoric occupations or a single continuous one. The archaeological evidence, however, does not seem consistent with either scenario, instead indicating a single occupation of relatively short duration (Carskadden 1992). When that suite of eight dates is tested statistically, they could have come from the same population. Comparison of the ceramic and lithic assemblages from Philo II with those from nearby Richards suggests it is closely allied to, but slightly predates, Richards (Figures 161 and 162); this is consistent with the radiocarbon sequence.

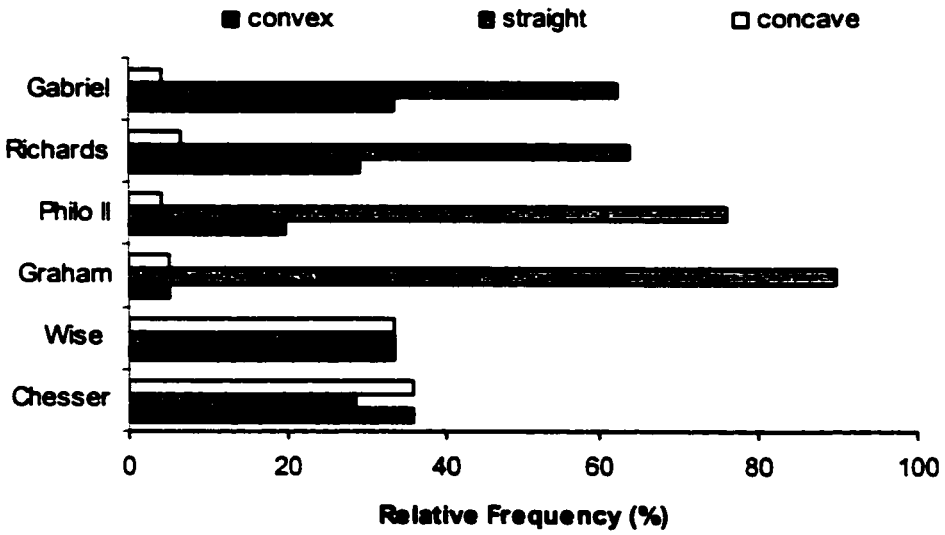


Figure 162. **Relative frequencies of triangular projectile point base forms.**

Although the dominant occupation at Baldwin was during the middle Late Prehistoric period, that locale was the site of occupations during the early Late Prehistoric and perhaps the Late Woodland period, as well (Murphy 1975). The radiocarbon date suggests that the middle Late Prehistoric occupation at Baldwin slightly postdated that at Richards, while those at Gabriel and Riker are even still more recent. Note, however, that in terms of ceramic surface treatment and projectile point base form, Gabriel seriates quite closely with Richards; the radiocarbon determination may not be an accurate indicator of the age of the

occupation there. Indeed, Graybill (1981) found that Gabriel seriated pretty consistently with assemblages that were dated ca. A.D. 1350, approximately one century earlier than the calibrated intercept for the radiocarbon date, but within its 2σ error range. Murphy (1975) notes that there were other, minor occupations at Gabriel during the Middle and Late Woodland and that there may have been a late Late Prehistoric one there, as well. I, with Graybill and Murphy, accept A.D. 1350 as the best estimate for the age of the dominant occupation there.

A periodized summary of these data is presented in Table 23. Late Woodland deposits are particularly well-represented in this area, even if they are primarily special-use sites (burial mounds and rockshelters). In contrast, late Late Prehistoric occupations are rare and this is apparently an accurate reflection of the archaeological record of the area (Murphy 1975).

Table 23. Summary of occupational history for Sequence IX, the Muskingum and Hocking Rivers.

Late Woodland	early Late Prehistoric	middle Late Prehistoric	late Late Prehistoric
Henderson Mnd	Graham Village	Philo II	Riker
Peters Cave	*Philo II?*	Richards	
Wise Shelter	*Chesser Cave*	Baldwin	
Chesser Cave	*Baldwin*	Gabriel	
Philo II	*Gabriel*	*Graham Village*	

Sequence X: Kentucky & Licking Rivers and Paint Creek Systems

The radiocarbon sequence for this area is shown in Figure 163. Three locales lack ^{14}C dates. Attempts had been made to acquire radiocarbon dates from one of those locales, DeVary; all three determinations were modern and consequently were rejected by Turnbow et al. (1983). Several TL dates (Figure 164) indicate occupation there during the late Late Prehistoric period. The artifact

assemblage, similar to that from the well-dated Goolman locale (Turnbow et al. 1983), is consistent with that assessment.

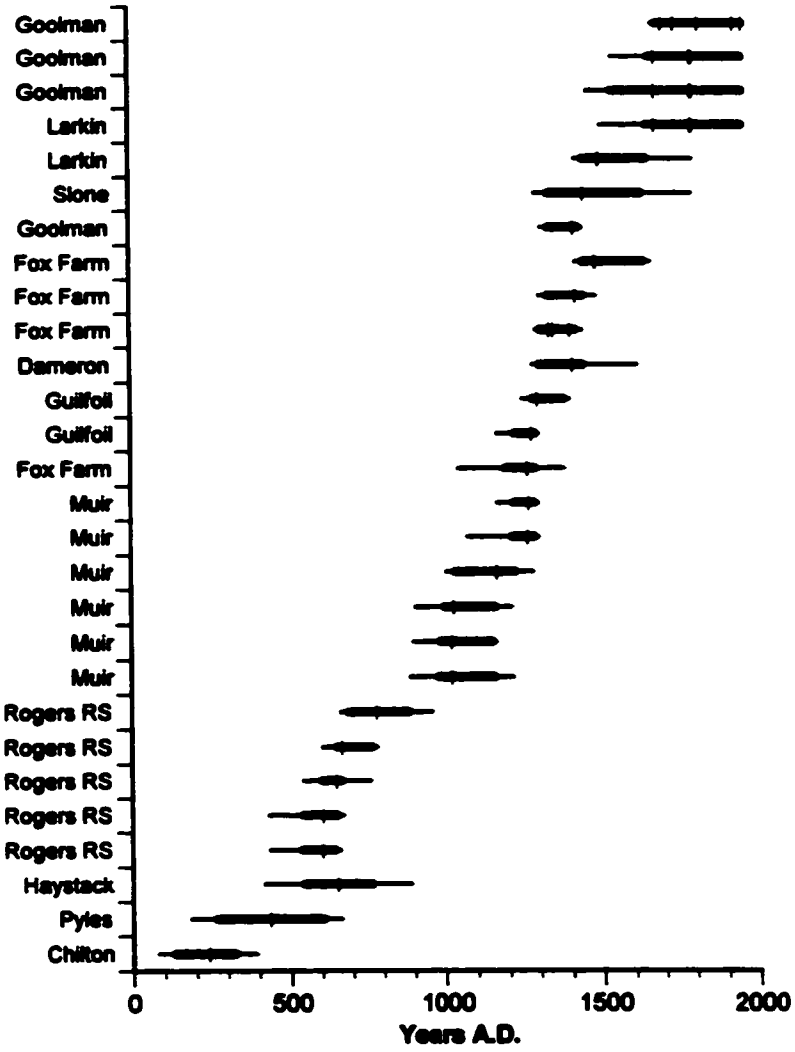


Figure 163. **Calendrical ages for Sequence X, the Kentucky and Licking Rivers and Paint Creek area.**

The ages of the other two locales without radiocarbon dates are somewhat more difficult to assess. There are two spatially and temporally distinct villages at Buckner, one occupied during the middle Late Prehistoric period and the other during the late Late Prehistoric period (Sharp 1990). The excavations that

produced the skeletal remains analyzed isotopically by Schurr (1998) are believed to have come from the later village. The other undated locale, Capitol View, is estimated to date to roughly A.D. 1400 and/or after (Schurr 1998), making it a late Late Prehistoric occupation, as well.

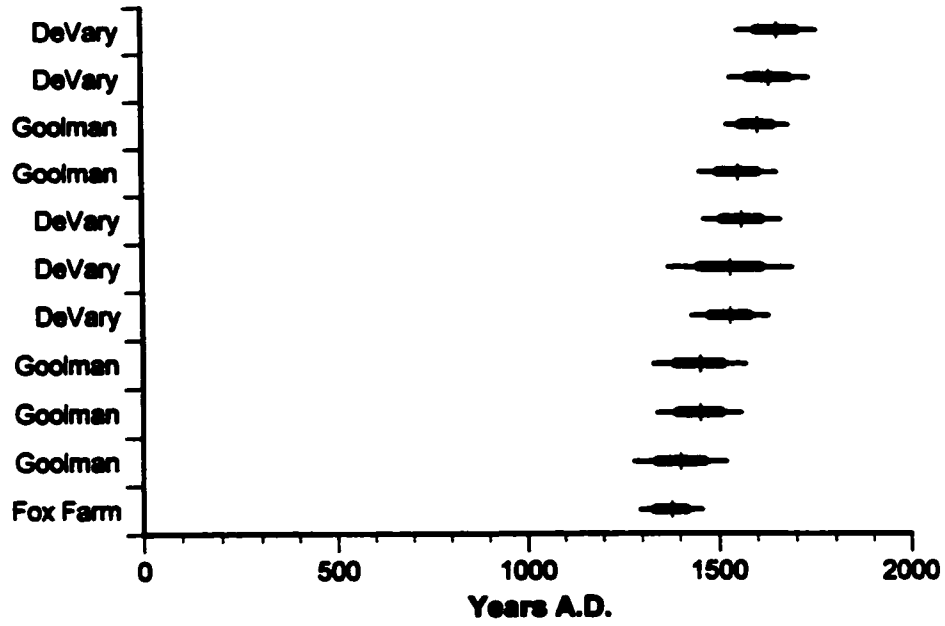


Figure 164. **Accepted TL dates for locales in the Kentucky and Licking River systems.**

A single radiocarbon date was obtained for Haystack Rockshelters. As shown in Figure 163, it was essentially identical to the suite of dates obtained from the nearby Rogers Rockshelters. The Rogers dates, on uncharred nutshell, place its occupation during the Late Woodland period; most of the dates fall early within the period, and the ceramic and lithic artifacts are consistent with that age assignment. In support of the radiocarbon determination from Haystack, Cowan (1979a) noted that the ceramic and lithic assemblages were nearly identical with those of Rogers, suggesting that these two rockshelter locales were occupied closely in time.

The single radiocarbon determinations from Pyles and Slone seem to be roughly consistent with archaeological evidence for the timing of their occupations. At the Pyles locale, the artifact assemblages are similar to those from other dated early Late Woodland occupations, in agreement with the single radiocarbon date (Railey 1984). Two TL dates from Pyles were rejected as too recent; there was no other evidence to support an early Late Prehistoric occupation there. Archaeological evidence recovered from Slone indicates that, during the middle Late Prehistoric period, three consecutively larger villages occupied that locale (Dunnell 1972; Dunnell et al. 1971). Both radiocarbon dates from Guilfoil are consistent with a single middle Late Prehistoric occupation there.

Chilton is commonly regarded as a Late Woodland cemetery (Clay 1984; Kellar 1960), yet radiocarbon dates to confirm that supposition have been lacking. As part of this research, I submitted bone samples from Chilton to Lawrence Livermore Lab for AMS dating. Although my tests of sample quality indicated that most of the bones in my sample from Chilton have an adequate amount of "collagen," they proved extremely difficult to date. I suspect that part of the problem may have been that the organic fraction of the bones was extremely fragmented; Lawrence Livermore uses an ultrafiltration step in their extraction protocol ([Brown et al. 1988]; see Appendix D) that removes peptides smaller than 30 kD molecular weight. The date from Chilton is plotted in Figure 163. Another, much older, determination was obtained on a second bone sample that appeared to have been thickly coated with a consolidant, possibly Alvar; as part of an as-yet-uncompleted test on the effectiveness of sample pretreatments at removing preservatives, it will not be considered here. At this point, Chilton appears to be a Middle Woodland deposit.

The radiocarbon date from Dameron Rockshelter in Figure 163 is one of several obtained from this multicomponent deposit (Vento et al. 1980). The rockshelter contained cultural materials interpreted as reflecting its intermittent

use from at least the Late Archaic period through the Historic era. Although there was evidence for some bioturbation throughout the deposit, radiocarbon determinations were stratigraphically consistent. Disturbance was most severe in the uppermost stratum, which contained Late Woodland/Late Prehistoric materials and those materials are assumed to be mixed.

Several other locales were sites of multiple occupations. Radiocarbon determinations from each of Fox Farm, Muir and Goolman subdivide into two significant clusters, indicating perhaps two occupations at each. The artifact assemblages from Fox Farm clearly support the presence of a minor middle Late Prehistoric in addition to the well-documented late Late Prehistoric occupation there. Because both clusters of dates from Muir are so close temporally, it may be that they reflect a single, somewhat long, occupation, rather than two discrete events. Archaeological evidence would seem to support the former, but it is not at all decisive (Turnbow and Sharp 1988). At Goolman, Archaic, Early Woodland and Late Woodland occupations were documented, in addition to the major occupation(s) during the late Late Prehistoric period. Both the TL and radiocarbon records from Goolman are consistent with two Late Prehistoric occupations there; archaeological evidence does not clearly contradict nor clearly support such a conclusion (Turnbow et al. 1983). Table 24 presents a summary of the occupational history for this area.

Table 24. Summary of occupational history for Sequence X, the Kentucky and Licking Rivers and Paint Creek vicinities.

Late Woodland	early Late Prehistoric	middle Late Prehistoric	late Late Prehistoric
Pyles	Muir	Guilfoil	Fox Farm
Rogers RS		Dameron	Larkin
Haystack RS		*Fox Farm*	Goolman
Dameron		*Goolman*	DeVary
Goolman		Slone	Capitol View
			Buckner

Sequence XI: The Kanawha, Guyandotte and New River Systems

The radiocarbon sequence from the vicinity of the Kanawha and Guyandotte Rivers is presented in Figure 165. All four of the locales considered here have multiple ^{14}C dates, yet for only one, Mt. Carbon, are they similar enough to represent a single statistical population. Although the ceramic and lithic assemblages also reflect earlier occupations at Mt. Carbon, they are dominated by Late Prehistoric materials (McMichael 1962). Thus, the major, but not the only, occupation at this locale probably occurred during the early Late Prehistoric period.

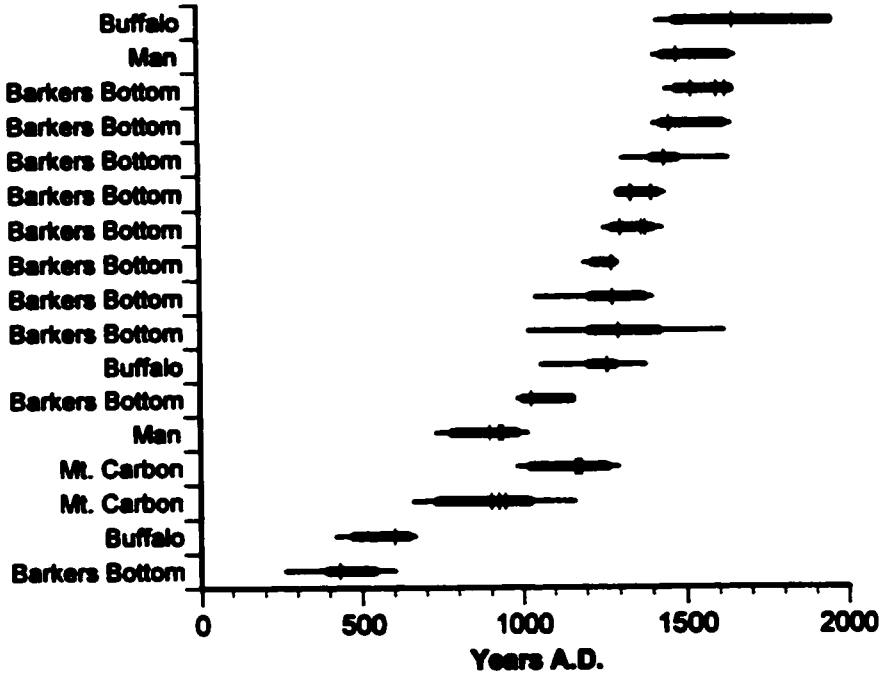


Figure 165. **Calendrical ages for Sequence XI, the Kanawha, Guyandotte and New River systems.**

Similarly, both Buffalo and Man experienced multiple occupations (and this is reflected in their radiocarbon dates), but late Late Prehistoric materials dominate their assemblages (Hanson 1975; Moxley and Bloemker 1985).

The ^{14}C dates from Barker's Bottom are somewhat problematic. Archaeological evidence (from a limited spatial sample) seems to indicate a single early Late Prehistoric occupation (Applegarth et al. 1978); their one date (SI-3421, the fourth from the bottom of the Barker's Bottom dates in Figure 165) reported with the results of that small excavation is consistent with the artifactual evidence recovered. Clearly, however, the rest of the ^{14}C determinations (Jones 1987) represent at least three, and probably four, statistical populations. Presumably, as a larger area is explored there, persuasive evidence for multiple occupations will be reported.

Table 25 summarizes the occupational history of this area. Although there are multiple occupations at each locale, each is dominated by materials of a particular time period. Mt. Carbon is primarily an early Late Prehistoric occupation, while the major occupations at Man and Buffalo occurred during the late Late Prehistoric periods. The published artifact descriptions from Barker's Bottom are consistent with an early Late Prehistoric occupation; yet debris from other occupations is probably concentrated elsewhere at that locale. Since the available subsistence data are from that portion of the locale described as an early Late Prehistoric deposit, it will be considered the primary occupation for the purposes of this research.

Table 25. Summary of occupational history for Sequence XI, the Kanawha, Guyandotte and New Rivers.

Late Woodland	early Late Prehistoric	middle Late Prehistoric	late Late Prehistoric
Barkers Bottom	Mt. Carbon	*Barkers Bottom*	*Barkers Bottom*
Buffalo	*Man*		Man
	Buffalo		Buffalo
	Barkers Bottom		

Sequence XII: The Scioto River System

The radiocarbon sequence from the final subarea considered here is presented in Figure 166. Only one locale, Continental Construction has a single date relevant to this study; it appears to be consistent with archaeological evidence for the age of the deposit. Of the locales with multiple dates, only Howard Baum and the Enos Holmes Mound appear to be straightforward. One of the dates from Enos Holmes was acquired, as part of this research, on bone from one of the burials in the mound; it was consistent with the existing early Late Prehistoric date from there.

In contrast, a new date on skeletal materials from W.S. Cole was found to be significantly earlier than other dates from there using charred wood. This indicates that that locale was used for mortuary purposes during the Late Woodland period, prior to the main, middle Late Prehistoric occupation there. Such a scenario probably accounts also for the disparate series of dates at the nearby Ufferman locale, albeit with different implications. Although ceramic analyses (Barkes 1982) and radiocarbon dates placed occupations at Ufferman to the Late Woodland and Late Prehistoric periods, a new radiocarbon date on a sample of human skeletal material from one of the burials there places its use as a mortuary site to the Late Archaic period. Thus, the skeletal material at Ufferman is significantly older that the time period of interest here. Not surprisingly, isotopic analyses of individuals indicate they had not consumed significant maize.

The determinations from Waterplant can be separated into two clusters visually, but statistically they could all reflect the same population. Archaeological evidence is generally consistent with the notion of a single occupation there (Church 1987; Dancey 1988). The determinations from Zencor also appear to separate into two clusters, with one outlier. Carr and Haas (1996) suggest that the outlier, the latest date in the series, should be rejected on the grounds that it is significantly later than the rest. Archaeologically, Zencor appears

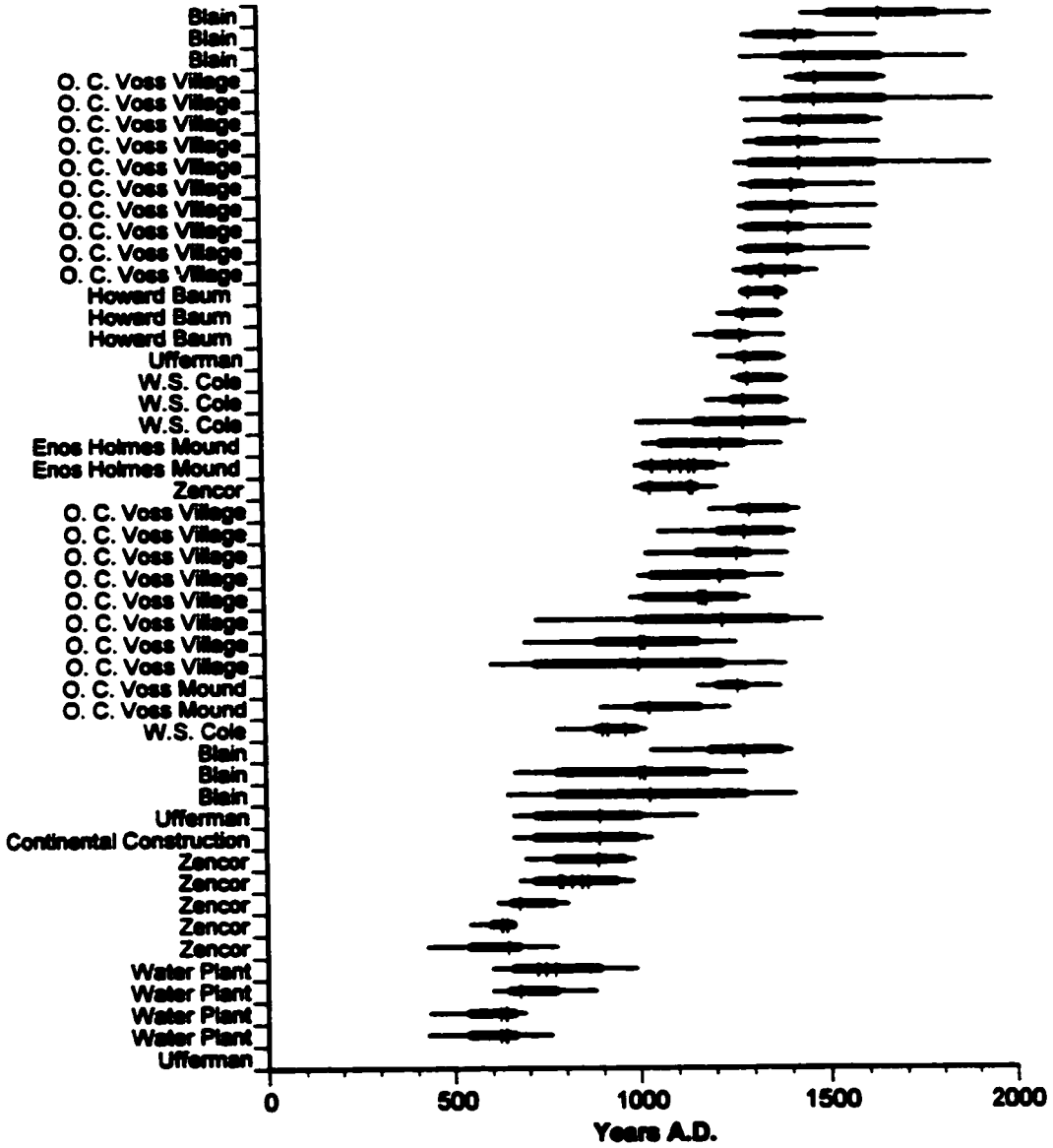


Figure 166. **Calendrical ages for Sequence XII, the Scioto Valley locales.**

to be a single component Late Woodland occupation (Barkes 1982; Church 1987) and so, in the absence of other data to the contrary, that late date has been eliminated from consideration here. The time span covered by ^{14}C dates from these two locales (Waterplant and Zencor) is virtually identical.

The village and mound at the O. C. Voss locale (Baby et al. 1966, 1967) are treated separately here. The mound is represented by two dates (one obtained on human bone as part of this research), both of which are consistent in placing its use to the early Late Prehistoric period. Artifacts recovered from the mound support that assessment. Radiocarbon determinations from the village appear to document two occupations, one coeval with the use of the mound during the early Late Prehistoric period, and one later during the middle Late Prehistoric period. Carr and Haas (1996) note, however, that this conflicts with artifactual evidence that suggests a single early Late Prehistoric occupation (Baby et al. 1967). Given that there are no subsistence analyses published for O. C. Voss, the only data relevant to the problem come from the skeletal remains from the mound; problems dating the village are not relevant and thus, I consider the locale as an early Late Prehistoric deposit.

A similar problem is presented by the radiocarbon sequence from Blain (Carr and Haas 1996). Again, two, possibly three, occupations are reflected by the dates, but the artifact assemblages are suggested to indicate a single early Late Prehistoric occupation (Prufer and Shane 1970). There is a problem with the most recent date in the series (namely, its $\delta^{13}C$ value is too depleted for the source material) and thus, the accuracy of the determination is open to question (Carr and Haas 1996). For that reason, I have rejected that date here. Even so, the age of the occupation at Blain is still somewhat unclear. Although the argument has been made, based on the artifact assemblages, that the occupation at Blain occurred at the end of the Late Woodland period or early in the early Late Prehistoric period (Church 1987; Prufer and Shane 1970), the radiocarbon evidence seems to be more consistent with an occupation later within the early Late Prehistoric period. That is how I treat Blain.

Four locales (Baum, Gartner, Cramer and Feurt) are without radiocarbon determinations. Church (1987) provides data on the relative

frequencies of triangular projectile point base forms in the first three and two other radiometrically-dated assemblages. Figure 167 orders these data. I note that although Church assumes the opposite order (i.e., Voss and Blain are the oldest occupations in the group), the arrangement of Voss as younger than Blain is consistent with radiocarbon evidence and the pattern of changing frequencies of the different point bases is consistent with that in the Muskingum Valley shown in Figure 162. Based on artifact descriptions, it seems clear that these occupations are all quite close in age. That the occupations at Cramer, Baum and Gartner are early Late Prehistoric in age is consistent with what is known of their ceramic assemblages, as well. Feurt was probably occupied somewhat later, during the middle Late Prehistoric period (cf. Schurr and Schoeninger 1995).

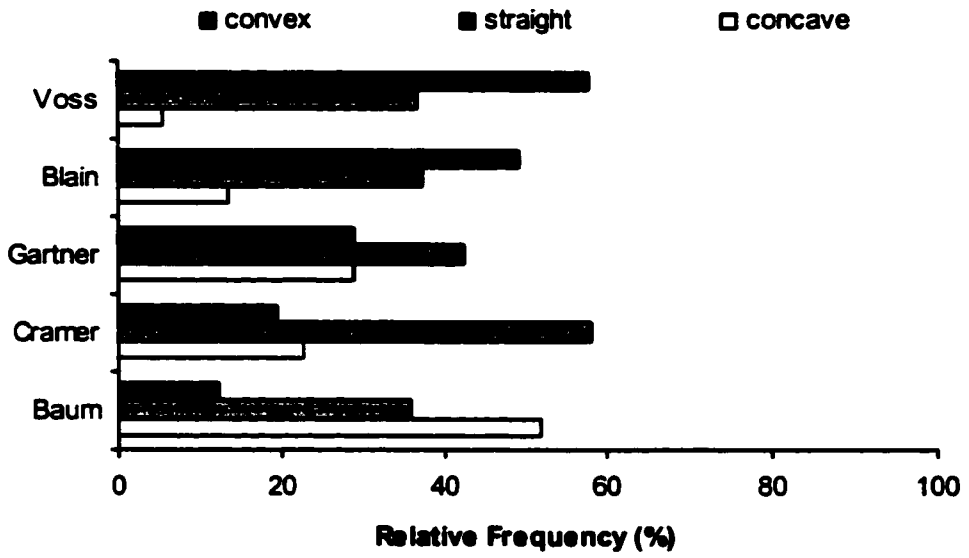


Figure 167. **Relative frequencies of triangular projectile point base forms.** Locales are arranged with apparent oldest at the bottom.

Table 26 periodizes the occupational history of the Scioto River valley. The table reflects the ambiguities presented by the artifactual and radiocarbon evidence for several locales.

Table 26. Summary of occupational history for Sequence XII, the Scioto River valley.

Late Woodland	early Late Prehistoric	middle Late Prehistoric	late Late Prehistoric
WaterPlant	Cramer	*W. S. Cole*	*Blain?*
Zencor	O. C. Voss Mound	*Blain?*	
Ufferman	O. C. Voss Village	*Ufferman*	
W. S. Cole	Blain	Howard Baum	
Cont. Constr.	Baum	O. C. Voss Village	
	Gartner	Feurt	
	Enos Holmes Mound		

Other Middle Ohio River Valley Materials

There are two Middle Valley locales for which I was not able to determine location beyond state and county. Skeletal materials from these locales were identified as to the relevant time period: Proctor Rockshelter dates to roughly A.D. 800 and is therefore a Late Woodland deposit (Sciulli et al. 1993). Rinehart is Late Woodland/early Late Prehistoric in age (Sciulli p.c.).

DEALING WITH TEMPORAL UNCERTAINTY

Many of the archaeobotanical, archaeofaunal and human skeletal assemblages that comprise this data set are the result of multiple depositional episodes. Data for only five Late Woodland/Late Prehistoric occupations (Haag, Madisonville, Saddle, Turpin and White Rocks) are actually separated on that basis. The midden at a sixth (Slone) has three arbitrarily subdivided levels which provide limited temporal resolution. For many others, there is no way to establish what proportions of the assemblages from these palimpsests were associated with any particular occupation; thus hundreds of years of subsistence exploitation may be collapsed into one accounting. This introduces noise and obscures potentially valuable information regarding temporal variation in resource exploitation.

My initial approach, when examining temporal variation in any subsistence parameter, was to look first at the best case scenario: those assemblages from single-occupation deposits and where the deposits have been temporally subdivided. As other assemblages (e.g., from deposits where a single occupation appeared to dominate other material types) were added, I watched to see what effect those assemblages have on any emerging patterns. When dealing with the human skeletal remains, I place greatest emphasis on those cases where dates have been acquired for particular individuals.

In addition to the complexity introduced by the occupational record, I have three different scales of chronological data that offer varying precision with respect to the temporal conclusions that may be drawn. Although absolute dates are to be preferred, only roughly 71% of the locales have radiometric determinations. Thus, relative comparisons among artifact assemblages must be a necessary part of my chronology construction. Since the artifact assemblages are typically summaries and are generally not broken down according to particular occupations, these comparisons are often accordingly sloppy. Finally, the periodized summaries attempt to include both dated and undated occupations, but temporal resolution is lost in the process. The benefits and liabilities of these different chronological schemes will be reflected in the different roles they play in my examination of temporal and environmental variation in subsistence.

Although in discussion it is easily recognized that establishing the age of archaeological assemblages is fairly inexact, this character is more difficult to incorporate into plots and statistical analyses of data, particularly when many data points are involved. The general procedure used by archaeologists is to assign a calendrical age to each assemblage, plot them accordingly, and then disregard any error that was associated with that age estimation. That is not the approach used here. In Table 27, I present the time period, calendrical age range and calendrical age for each assemblage used in plots and statistical analyses. Estimated

calendrical ages are based on radiometric dates and artifact comparisons with other assemblages. Calendrical age estimates are employed primarily for plotting purposes; statistical analyses routinely use nonparametric techniques to examine variables across time periods.

Table 27. Summary of chronological assignments for dietary and/or subsistence data used in this research.

Name	Period[1]	Calendrical Age[2]	Cal. Age Range[2]
36AR?	LW	--	--
46BR2	LP	--	--
46OH1	LP	--	--
46OH13	eLP	A.D. 1050	A.D. 1000 – 1250
Anderson Village	mLP	A.D. 1280	A.D. 1220 – 1380
A. M. Byers	LW	--	--
Ashmore Farm	LP	--	--
Augusta	lLP	A.D. 1440	A.D. 1400 – 1600
Baldwin	mLP	A.D. 1340	A.D. 1290 – 1400
Barker's Bottom			
Fauna and Flora	eLP	A.D. 1100	A.D. 1000 – 1300
Human Burials	mLP, lLP	A.D. 1270, 1450	
Barn	LP	--	--
Baum	eLP	A.D. 1100	A.D. 1000 – 1250
Blain Village	eLP	A.D. 1240	A.D. 900 – 1350
Bonnie Brook	lLP	A.D. 1410	A.D. 1300 – 1600
Boyle	eLP	A.D. 1260	A.D. 1170 – 1290
Britt Bottom	mLP	A.D. 1290	A.D. 1260 – 1380
Buckner	lLP	A.D. 1400	A.D. 1350 – 1500
Buffalo	lLP	A.D. 1600	A.D. 1480 – 1700
Bunnel Kame	mLP, lLP	A.D. 1360, 1410	A.D. 1300 – 1430
Bunola	mLP	A.D. 1350	A.D. 1290 – 1430
Campbell Farm	mLP	A.D. 1310	A.D. 1220 – 1450
Campbell Island	lLP	A.D. 1430	A.D. 1330 – 1490

Table 27 (continued).

Name	Period[1]	Calendrical Age	Cal. Age Range
Capitol View	lLP	A.D. 1410	A.D. 1350 – 1550
Carroll-Oregonia Road	lLP	A.D. 1430	A.D. 1330 – 1480
Chesser Cave	LW	A.D. 650	A.D. 400 – 1000
Childers			
Fauna and Flora	LW	A.D. 585	A.D. 350 – 900
Human Burials	eLP	A. D. 1000	A.D. 800 – 1100
Chilton	MW	A.D. 240	A.D. 130 – 320
C. L. Lewis	EW	300 B.C.	390 – 200 B.C.
Cleek-McCabe	eLP	A.D. 1220	A.D. 1050 – 1280
Continental Construction	LW	A.D. 890	A.D. 720 – 990
Cramer	eLP	A.D. 1125	A.D. 1000 – 1250
Dameron Rockshelter	mLP	A.D. 1400	A.D. 1300 – 1440
DeVary	lLP	A.D. 1600	A.D. 1500 – 1650
Drew	eLP	A.D. 1220	A.D. 1100 – 1280
Duvall	mLP	A.D. 1290	A.D. 1260 – 1380
Elliot	LP	--	--
Enos Holmes Mound	eLP	A.D. 1120	A.D. 1020 – 1200
Felix	LP	--	--
Feurt	mLP	A.D. 1325	A.D. 1250 – 1400
Finley	lLP	A.D. 1570	A.D. 1400 – 1650
Foster	LP	--	--
Fox Farm	lLP	A.D. 1450	A.D. 1350 – 1550
Francis	mLP	A.D. 1350	A.D. 1250 – 1400
Fuller's Hill	mLP	A.D. 1350	A.D. 1300 – 1420
Gabriel	mLP	A.D. 1350	A.D. 1300 – 1500
Gartner	eLP	A.D. 1150	A.D. 1000 – 1250
Globe Hill Shell Heap	MW/LW	--	--
Gnagey	eLP	A.D. 1150	A.D. 900 – 1300
Godwin-Portman	mLP	A.D. 1280	A.D. 1220 – 1380
Goolman	lLP	A.D. 1550	A.D. 1400 – 1700
Graham Village	mLP	A.D. 1270	A.D. 1070 – 1390

Table 27 (continued).

Name	Period[1]	Calendrical Age	Cal. Age Range
Guard	eLP	A.D. 1200	A.D. 1060 – 1260
Guilfoil	mLP	A.D. 1280	A.D. 1220 – 1380
Hansen	LW	A.D. 560	A.D. 300 – 750
Hardin Village	lLP	A.D. 1600	A.D. 1450 – 1650
Hartley	lLP	A.D. 1600	A.D. 1580 – 1615
Hawkins Ridge	LW	A.D. 890	A.D. 780 – 980
Haystack Rockshelters	LW	A.D. 650	A.D. 540 – 760
Henderson Mound #2	LW	A.D. 440	A.D. 380 – 560
Henderson Rocks	mLP	A.D. 1280	A.D. 1250-1350
Hobson	eLP	A.D. 1150	A.D. 1100 – 1200
Horseshoe Johnson	mLP	A.D. 1270	A.D. 1220 – 1280
Household	lLP	A.D. 1570	A.D. 1450 – 1630
Howard Baum	mLP	A.D. 1310	A.D. 1220 – 1390
Hughes Farm	eLP	A.D. 1200	A.D. 1000 – 1250
Incinerator	mLP	A.D. 1300	A.D. 1200 – 1400
Johnston	mLP	A.D. 1290	A.D. 1260 – 1390
Kelso	mLP	A.D. 1350	A.D. 1300 – 1410
Killen	mLP	A.D. 1300	A.D. 1100 – 1400
King	LP	--	--
Larkin	lLP	A.D. 1490	A.D. 1440 – 1640
Laughlin	lLP	A.D. 1550	A.D. 1450 – 1650
Leonard Haag			
Late Woodland	LW	A.D. 540	A.D. 300 – 860
Late Prehistoric	mLP	A.D. 1290	A.D. 1220 – 1400
Madisonville			
Early	mLP	A.D. 1300	A.D. 1280 – 1450
Late	lLP	A.D. 1600	A.D. 1450 – 1650
Man	lLP	A.D. 1480	A.D. 1440 – 1600
McJunkin	mLP	A.D. 1350	A.D. 1280 – 1420
McKees Rocks Village	mLP	A.D. 1350	A.D. 1280 – 1420
Middle Site Island	eLP	A.D. 1200	A.D. 1000 – 1250
Miller	eLP	A.D. 1210	A.D. 1030 – 1280

Table 27 (continued).

Name	Period[1]	Calendrical Age	Cal. Age Range
Mon City	lLP	A.D. 1470	A.D. 1350 – 1600
Montague	eLP	A.D. 1000	A.D. 900 – 1100
Mount Carbon	eLP	A.D. 1200	A.D. 1000 – 1300
Muir	eLP	A.D. 1125	A.D. 980 – 1280
Newtown Firehouse	LW	A.D. 1020	A.D. 990 – 1100
O.C. Voss	eLP	A.D. 1250	A.D. 1000 – 1280
Oglesby-Harris	eLP	A.D. 1170	A.D. 1040 – 1260
Ohioview	LP	--	--
Peters Cave	LW	A.D. 650	A.D. 400 – 1000
Philo II	mLP	A.D. 1270	A.D. 1050 – 1400
Pinnacle	mLP	A.D. 1310	A.D. 1250 – 1400
Portman	mLP	A.D. 1400	A.D. 1310 – 1440
Proctor Rockshelter	LW	A.D. 800	A.D. 400 – 1000
Pyles	LW	A.D. 430	A.D. 270 – 600
Raven Rocks	LW	A.D. 980	A.D. 780 – 1020
Reservoir	LP	--	--
Richards	mLP	A.D. 1310	A.D. 1270 – 1400
Riker	lLP	A.D. 1460	A.D. 1400 – 1650
Rinehart	LW/eLP		
Rochester	lLP	A.D. 1620	A.D. 1610 – 1635
Rogers Rockshelters	LW	A.D. 660	A.D. 440 – 880
Roseberry Farm	eLP	A.D. 1170	A.D. 1000 – 1300
Ryan	eLP	A.D. 1120	A.D. 990 – 1280
Saddle			
Early	eLP	A.D. 1180	A.D. 1000 – 1280
Late	mLP	A.D. 1370	A.D. 1250 – 1400
Sand Ridge			
Late Woodland	LW	A.D. 780	A.D. 450 – 1020
Late Prehistoric	mLP	A.D. 1300	A.D. 1250 – 1400
Scarem	mLP	A.D. 1290	A.D. 1250 – 1400
Schomaker	mLP	A.D. 1370	A.D. 1280 – 1450
Shippenport	lLP	A.D. 1450	A.D. 1400 – 1500

Table 27 (continued).

Name	Period[1]	Calendrical Age	Cal. Age Range
Slone	lLP	A.D. 1440	A.D. 1350 – 1550
Snag Creek	lLP	A.D. 1450	A.D. 1400 – 1500
Sony	lLP	A.D. 1600	A.D. 1580 – 1615
State Line	mLP	A.D. 1280	A.D. 1210 – 1380
Thompson	eLP	A.D. 1150	A.D. 1000 – 1250
Tower	mLP	A.D. 1350	A.D. 1300 – 1410
Turpin			
Late Woodland	LW	A.D. 960	A.D. 540 – 980
Late Prehistoric	eLP	A.D. 1210	A.D. 1050 – 1280
Ufferman	LA	1350 B.C.	1410 – 1270 B.C.
Varner	LW	A.D. 920	A.D. 780 – 1100
Waterplant	LW	A.D. 650	A.D. 540 – 890
Watson	eLP	A.D. 1150	A.D. 1000 – 1250
White Rocks			
Late Woodland	LW	A.D. 670	A.D. 650 – 770
Late Prehistoric	eLP	A.D. 1100	A.D. 1000 – 1200
Wise Rockshelter	LW	A.D. 700	A.D. 600 – 900
Wood-73	eLP	A.D. 1020	A.D. 980 – 1200
Woods	LW	A.D. 870	A.D. 580 – 1030
W.S. Cole	LW	A.D. 930	A.D. 890 – 990
Wylie	mLP	A.D. 1290	A.D. 1260 – 1390
Zencor	LW	A.D. 690	A.D. 540 – 960

[1] LA, Late Archaic; EW, Early Woodland; MW, Middle Woodland; LW, Late Woodland; LP, Late Prehistoric; eLP, early Late Prehistoric; mLP, middle Late Prehistoric; lLP, late Late Prehistoric period.

[2] Insufficient data to establish calendrical age or age range indicated by --.

RADIOMETRIC DATA

Table 28 presents the set of published radiocarbon determinations used in this analysis; newly acquired ^{14}C determinations are presented in Table 29. Each has been calibrated with CALIB version 4.1.2 (Stuiver and Reimer 1993), using the decadal data set, Method A, and no lab error multiplier; radiocarbon ages

were assumed to be conventional (i.e., corrected for sample fractionation) unless otherwise stated in the publication.

Table 28. Published radiocarbon determinations, the materials dated, and their calibrated age ranges. Years B.C. are distinguished as negative values. Unreported data are indicated as --.

Lab code	Location	Material Dated[4]	^{14}C age ± 1 sd	Intercept(s)	σ	cal AD/BC[5] max	min
DIC-776[1]	Anderson	--	730 ± 100	1282	1	1218	1385
					2	1043	1413
Beta-11855	Augusta	charred wood	470 ± 90	1437	1	1403	1482
					2	1300	1640
Beta-18183	Augusta	charred wood	470 ± 70	1437	1	1408	1470
					2	1321	1627
Beta-13365	Augusta	charred wood	210 ± 60	1665,1784,1789	1	1645	1947
					2	1522	1951
Beta-17822	Baldwin	--	630 ± 80	1304,1367,1385	1	1286	1406
					2	1259	1437
DIC-1654	Barkers Bottom	--	1610 ± 60	428	1	395	536
					2	261	599
DIC-1655	Barkers Bottom	--	980 ± 45	1025	1	1005	1154
					2	983	1162
DIC-1556	Barkers Bottom	--	760 ± 45	1276	1	1225	1286
					2	1194	1298
SI-3421	Barkers Bottom	charcoal	745 ± 90	1279	1	1217	1377
					2	1044	1402
DIC-1555	Barkers Bottom	--	680 ± 165	1296	1	1214	1419
					2	1020	1616
UGa-5595	Barkers Bottom	human bone	638 ± 75	1303,1369,1382	1	1285	1403
					2	1259	1432
DIC-1653	Barkers Bottom	--	570 ± 55	1334,1336,1400	1	1305	1419
					2	1295	1439
DIC-1652	Barkers Bottom	--	470 ± 75	1437	1	1407	1475
					2	1311	1631
UGa-5596	Barkers Bottom	human bone	409 ± 60	1453	1	1436	1617
					2	1411	1640
SI-3422	Barkers Bottom	--	340 ± 40	1519,1594,1622	1	1480	1637
					2	1446	1649
OWU-248	Blain	charcoal	1035 ± 155	1002,1012,1016	1	784	1181
					2	664	1283
OWU-247B	Blain	charcoal	970 ± 220	1029	1	784	1278
					2	645	1413
M-1911	Blain	charcoal	760 ± 100	1276	1	1192	1376
					2	1033	1403
M-1910	Blain	charred wood	490 ± 100	1430	1	1329	1477
					2	1293	1640
OWU-247A	Blain	maize	405 ± 150	1454	1	1404	1650
					2	1288	1883

Table 28 (continued).

Lab code	Location	Material Dated[4]	^{14}C age ± 1 sd	Intercept(s)	σ	cal AD/BC[5] max	min
ETH-4501	Blain	charred nutshell	270 ± 75	1645	1	1517	1797
					2	1447	1949
UGa-1773	Bonnie Brook	charred wood	535 ± 105	1411	1	1302	1445
					2	1279	1629
UGa-1775	Bonnie Brook	charred wood	250 ± 115	1652	1	1488	1948
					2	1433	1954
UGa-1774	Bonnie Brook	charred wood	185 ± 65	1672,1778,1799, 1943,1945	1	1652	1949
					2	1528	1952
I-16765	Boyle	human bone	790 ± 80	1259	1	1165	1287
					2	1037	1385
UGa-301	Buffalo	charcoal	1490 ± 70	598	1	475	643
					2	420	664
UGa-303	Buffalo	charcoal	780 ± 70	1263	1	1211	1287
					2	1059	1382
UGa-304	Buffalo	bark	270 ± 120	1645	1	1476	1947
					2	1420	1954
DIC-1033[1]	Bunnell Kame	human bone	590 ± 60	1329,1343,1395	1	1300	1413
					2	1286	1437
DIC-1045	Bunnell Kame	human bone	540 ± 50	1409	1	1329	1431
					2	1302	1443
DIC-1043	Bunnell Kame	human bone	505 ± 45	1423	1	1405	1439
					2	1327	1451
M-2200	Bunola	charred wood	600 ± 100	1327,1346,1393	1	1290	1426
					2	1245	1470
--	Bunola	human bone	600 ± 80	1327,1346,1393	1	1296	1417
					2	1276	1443
SI-1323	Campbell Farm	--	1010 ± 95	1020	1	903	1157
					2	782	1221
DIC-2240	Campbell Farm	charred wood	780 ± 50	1263	1	1218	1283
					2	1163	1296
SI-3672	Campbell Farm	--	550 ± 60	1406	1	1322	1431
					2	1297	1445
M-2204	Campbell Farm	charcoal	520 ± 100	1416	1	1313	1449
					2	1284	1631
SI-1322	Campbell Farm	charred wood	425 ± 105	1446	1	1412	1631
					2	1303	1786
Beta-14222	Campbell Island	charred wood	540 ± 60	1409	1	1327	1435
					2	1299	1449
Beta-17995	Campbell Island	charred bean	440 ± 70	1443	1	1420	1486
					2	1331	1637
DIC-1042	Carroll-Oregonia Road	charcoal	480 ± 90	1434	1	1334	1477
					2	1299	1637
OWU-180	Chesser Cave	charcoal	880 ± 140	1163,1173,1180	1	1018	1280
					2	889	1393
Beta-27276	Childers	charred nutshell	2060 ± 60	-50	1	-167	16
					2	-345	71
Beta-27278	Childers	charred wood	1660 ± 70	407	1	261	434
					2	237	556

Table 28 (continued).

Lab code	Location	Material Dated[4]	^{14}C age ± 1 sd	Intercept(s)	σ	cal AD/BC[5] max	min
Beta-22789	Childers	charred wood & nutshell	1610 ± 90	428	1	343	555
					2	240	641
Beta-27280	Childers	charred nutshell	1580 ± 70	437,454,457,522, 527	1	411	559
					2	263	639
SMU-2270	Childers	charred nutshell & meat	1470 ± 110	602	1	436	662
					2	359	775
Beta-27279	Childers	charred wood	1470 ± 80	602	1	536	656
					2	420	688
Beta-27277	Childers	charred wood	1450 ± 80	620,634,636	1	540	660
					2	427	759
SMU-2254	Childers	charred wood & nutshell	1440 ± 70	623,628,638	1	544	660
					2	435	690
SMU-2224	Childers	charred nutshell & meat	1380 ± 70	658	1	618	687
					2	541	777
Beta-22397	Childers	charred wood	1330 ± 80	674	1	645	775
					2	565	888
SMU-2269	Childers	charred wood	1300 ± 65	689	1	660	777
					2	640	888
SMU-2223	Childers	charred nutshell & meat	1250 ± 65	773	1	685	883
					2	657	959
DIC-1882	Childers	--	1210 ± 60	781,793,802	1	695	892
					2	670	980
UGa-5597	Childers	human bone	1092 ± 93	978	1	784	1022
					2	693	1159
DIC-1881	Childers	charcoal	890 ± 60	1161	1	1037	1219
					2	1019	1276
UGa-2637	Childers	--	885 ± 90	1162	1	1026	1258
					2	985	1289
DIC-1498	Childers	--	790 ± 60	1259	1	1211	1283
					2	1070	1298
DIC-1496[1]	Childers	human bone	750 ± 55	1278	1	1225	1292
					2	1190	1382
RL-216	Cleek McCabe	*human bone*	1680 ± 100	388	1	242	527
					2	127	601
RL-217	Cleek McCabe	*human bone*	1220 ± 90	779	1	686	942
					2	651	1015
RL-218	Cleek McCabe	*human bone*	830 ± 90	1218	1	1060	1281
					2	1019	1379
ETH-3309	Continental Construction	charred wood & nutshell	1160 ± 100	890	1	723	992
					2	661	1034
S1-3680	Dameron	charcoal	560 ± 100	1403	1	1299	1439
					2	1276	1609
M-2198[2]	Drew	maize	847 ± 108	1216	1	1038	1282
					2	995	1387
Beta-141	Drew	--	830 ± 50	1218	1	1163	1263
					2	1042	1283
Beta-31450	Drew	--	810 ± 60	1224,1231,1239	1	1165	1279
					2	1042	1294

Table 28 (continued).

Lab code	Location	Material Dated[4]	^{14}C age ± 1 sd	Intercept(s)	σ	cal AD/BC[5] max	min
UW-561	Duvall	charcoal	745 ± 45	1279	1	1259	1291
					2	1215	1378
UW-562	Duvall	charcoal	695 ± 55	1292	1	1278	1382
					2	1224	1397
OWU-276	Enos Holmes Md	--	815 ± 95	1222	1	1070	1284
					2	1020	1386
M-1086	Erp	--	515 ± 75	1418	1	1329	1443
					2	1298	1606
M-831	Erp	--	470 ± 150	1437	1	1314	1631
					2	1269	1946
Beta-13363	Fox Farm	charred wood	790 ± 70	1259	1	1191	1284
					2	1042	1379
Beta-13364	Fox Farm	charred wood	590 ± 60	1329,1343,1395	1	1300	1413
					2	1286	1437
Beta-11857	Fox Farm	charred wood	530 ± 70	1412	1	1327	1439
					2	1297	1478
Beta-11856	Fox Farm	charred wood	390 ± 70	1476	1	1438	1631
					2	1411	1652
--	Fuller's Hill	human bone	600 ± 80	1327,1346,1393	1	1296	1417
					2	1276	1443
OWU-253	Gabriel	charcoal	425 ± 155	1446	1	1332	1645
					2	1281	1949
CWR-184	Globe Hill	deer bone	4120 ± 220	-2834,-2819,	1	-2917	-2353
				-2662,-2648,-2625	2	-3352	-2036
--	Gnagey[3]	charred wood	1070 ± 80	984	1	892	1023
					2	778	1158
--	Gnagey[3]	charred wood	1000 ± 80	1021	1	981	1157
					2	889	1216
--	Gnagey[3]	charred wood	960 ± 75	1034	1	1002	1162
					2	901	1243
UGA-1599	Gnagey[3]	charred wood	945 ± 80	1039,1142,1150	1	1005	1207
					2	903	1262
--	Gnagey[3]	charred wood	880 ± 80	1163,1173,1180	1	1033	1256
					2	1000	1285
--	Gnagey[3]	charred wood	830 ± 75	1218	1	1074	1278
					2	1024	1296
	Gnagey[3]	charred wood	790 ± 75	1259	1	1189	1286
					2	1040	1382
AA29118	Gnagey	bean	635 ± 45	1303,1368,1383	1	1295	1396
					2	1282	1409
AA29117	Gnagey	bean	610 ± 35	1323,1350.1390	1	1298	1405
					2	1283	1428
GAK-5348	Gnagey[3]	charred wood	230 ± 70	1659	1	1484	1947
					2	1637	1950
M-2203	Godwin-Portman	charred wood	740 ± 100	1280	1	1215	1382
					2	1040	1410
DIC-2508	Goolman	charred bark	550 ± 40	1406	1	1329	1422
					2	1303	1438

Table 28 (continued).

Lab code	Location	Material Dated[4]	^{14}C age ± 1 sd	Intercept(s)	σ	cal AD/BC[5] max	min
DIC-2338	Goolman	charred wood	210 ± 100	1665,1784,1789	1	1531	1949
					2	1452	1955
DIC-2509	Goolman	charred bark	210 ± 50	1665,1784,1789	1	1648	1947
					2	1530	1949
DIC-2339	Goolman	charred wood	130 ± 55	1689,1729,1810, 1922,1948	1	1672	1951
					2	1656	1954
OWU-183	Graham Village	charred wood	770 ± 145	1271	1	1067	1386
					2	990	1435
OWU-184	Graham Village	--	285 ± 220	1641	1	1423	1952
					2	1283	1955
Beta-17992	Guard	--	860 ± 60	1192,1199,1208	1	1060	1256
					2	1024	1281
Beta-18186	Guilfoil	charcoal	770 ± 50	1271	1	1220	1285
					2	1164	1298
Beta-18185	Guilfoil	charcoal	700 ± 50	1290	1	1278	1379
					2	1243	1394
Beta-15511	Hansen	--	1770 ± 90	245,310,315	1	131	389
					2	34	434
Beta-15510	Hansen	--	1630 ± 100	421	1	261	540
					2	178	641
Beta-15082	Hansen	--	1630 ± 90	421	1	263	538
					2	235	636
Beta-14573	Hansen	--	1520 ± 60	542	1	435	618
					2	415	654
Beta-15084	Hansen	--	1510 ± 70	544,549,558	1	435	638
					2	410	660
Beta-15509	Hansen	--	1410 ± 80	646	1	598	676
					2	440	775
Beta-15512	Hansen	nutshell	1400 ± 70	652	1	602	676
					2	537	772
Beta-14575	Hansen	--	1360 ± 70	662	1	640	759
					2	561	780
M-2205	Hartley	charred wood	250 ± 100	1652	1	1515	1947
					2	1440	1953
Beta-56273	Hawkins Ridge	charcoal	1160 ± 60	890	1	779	977
					2	692	1015
GX-5875	Haystack RS	--	1405 ± 120	649	1	541	761
					2	414	889
I-16860	Henderson Md 2	charcoal	1600 ± 80	430	1	387	555
					2	256	639
UGa-1282	Henderson Rocks	charcoal	745 ± 55	1279	1	1255	1294
					2	1192	1384
UGa-1281	Henderson Rocks	charcoal	725 ± 55	1283	1	1262	1298
					2	1216	1389
UGa-1283	Henderson Rocks	charcoal	695 ± 70	1292	1	1274	1386
					2	1216	1405
I-14274	Hobson	--	600 ± 80	1327,1346,1393	1	1296	1417
					2	1276	1443

Table 28 (continued).

Lab code	Location	Material Dated[4]	^{14}C age ± 1 sd	Intercept(s)	σ	cal AD/BC[5] max	min
Beta-17993	Horseshoe Johnson	--	780 ± 50	1263	1	1218	1283
					2	1163	1296
--	Household	human bone	490 ± 80	1430	1	1334	1453
					2	1300	1522
UGa-3453	Household	charred wood	325 ± 80	1524,1562,1629	1	1454	1654
					2	1431	1946
ETH-4244	Howard Baum	charred wood	745 ± 75	1279	1	1221	1298
					2	1160	1395
DIC-1928[1]	Howard Baum		710 ± 50	1287	1	1276	1376
					2	1223	1391
SMU-1930	Howard Baum	charred wood	646 ± 41	1301,1371,1380	1	1293	1392
					2	1281	1403
RL-310	Hughes Farm	charcoal	1290 ± 90	691,703,708,753, 758	1	658	859
					2	602	963
CWR-148	Incinerator	--	900 ± 160	1160	1	991	1280
					2	779	1398
CWR-151	Incinerator	--	890 ± 100	1161	1	1023	1260
					2	978	1294
CWR-153	Incinerator	--	830 ± 130	1218	1	1033	1290
					2	979	1401
CWR-145	Incinerator	--	820 ± 155	1221	1	1026	1298
					2	896	1422
CWR-140[1]	Incinerator	--	820 ± 115	1221	1	1041	1289
					2	997	1396
CWR-141	Incinerator	--	800 ± 190	1256	1	1023	1390
					2	885	1449
Beta-20402	Incinerator	--	780 ± 60	1263	1	1215	1284
					2	1159	1376
CWR-156	Incinerator	--	770 ± 320	1271	1	979	1441
					2	645	1948
Beta-20401	Incinerator	--	660 ± 60	1299,1375	1	1284	1393
					2	1262	1410
M-1965	Incinerator	charcoal	640 ± 100	1302,1369,1382	1	1280	1409
					2	1215	1443
Beta-20403	Incinerator	--	560 ± 80	1403	1	1302	1435
					2	1284	1471
OWU-448B	Incinerator	--	555 ± 100	1404	1	1300	1440
					2	1277	1613
I-7087	Incinerator	--	395 ± 80	1473	1	1435	1633
					2	1404	1658
--	Johnston	human bone	700 ± 90	1290	1	1259	1390
					2	1163	1417
Beta-20777	Kelso	--	600 ± 60	1327,1346,1393	1	1299	1410
					2	1283	1435
DIC-857B	Killen	charred wood	780 ± 95	1263	1	1164	1295
					2	1028	1396
DIC-851	Killen	charcoal	750 ± 205	1278	1	1036	1407
					2	889	1622

Table 28 (continued).

Lab code	Location	Material Dated[4]	^{14}C age ± 1 sd	Intercept(s)	σ	cal AD/BC[5] max	min
DIC-853	Killen	charred wood	710 ± 205	1287	1	1067	1424
					2	899	1637
DIC-856	Killen	charcoal	640 ± 80	1302,1369,1382	1	1284	1403
					2	1244	1435
Beta-19068	Larkin	--	370 ± 80	1486	1	1440	1640
					2	1411	1790
Beta-19067	Larkin	--	210 ± 70	1665,1784,1789	1	1642	1948
					2	1494	1952
GX-2929	Leonard Haag	--	1910 ± 225	82	1	-171	385
					2	-401	617
GX-2928[1]	Leonard Haag	charred grass	1835 ± 150	139,150,176,192, 212	1	5	385
					2	-172	539
DIC-242	Leonard Haag	--	1670 ± 100	397	1	245	530
					2	129	603
DIC-241	Leonard Haag	--	1300 ± 100	689	1	651	859
					2	561	977
GX-2930	Leonard Haag	charred wood	950 ± 160	1037,1143,1148	1	902	1259
					2	695	1385
DIC-239	Leonard Haag	--	720 ± 120	1284	1	1215	1393
					2	1033	1435
DIC-240	Leonard Haag	--	680 ± 100	1296	1	1263	1398
					2	1163	1435
Uga-5285	Madisonville	charcoal	985 ± 90	1024	1	983	1161
					2	888	1251
AA-10216-1	Madisonville	maize	965 ± 110	1031	1	983	1211
					2	784	1280
Beta-45675	Madisonville	charcoal	710 ± 50	1287	1	1276	1376
					2	1223	1391
Beta-51847	Madisonville	charcoal	690 ± 50	1293	1	1280	1382
					2	1258	1396
AA-11774	Madisonville	maize	514 ± 66	1419	1	1331	1441
					2	1301	1482
AA-10218	Madisonville	maize	490 ± 55	1430	1	1407	1444
					2	1326	1483
AA-10219	Madisonville	maize	485 ± 45	1432	1	1412	1443
					2	1332	1477
UGa-4291	Madisonville	charcoal	475 ± 95	1436	1	1334	1482
					2	1298	1641
UGa-5287	Madisonville	charcoal	475 ± 95	1436	1	1334	1482
					2	1298	1641
AA-10221-1	Madisonville	maize	400 ± 55	1468	1	1439	1619
					2	1419	1640
AA-10220-1A	Madisonville	maize	400 ± 45	1468	1	1441	1613
					2	1428	1635
AA-10220-1B	Madisonville	maize	385 ± 40	1479	1	1445	1619
					2	1436	1636
AA-10215	Madisonville	maize	370 ± 45	1486	1	1450	1629
					2	1437	1642

Table 28 (continued).

Lab code	Location	Material Dated[4]	^{14}C age ± 1 sd	Intercept(s)	σ	cal AD/BC[5] max	min
AA-10220-2A	Madisonville	maize	325 ± 50	1524,1562,1629	1	1482	1644
					2	1445	1661
AA-10217	Madisonville	maize	315 ± 40	1528,1551,1633	1	1492	1644
					2	1469	1658
Beta-51846	Madisonville	charcoal	310 ± 70	1531,1545,1635	1	1480	1656
					2	1440	1946
Beta-45676	Madisonville	charcoal	300 ± 60	1637	1	1490	1656
					2	1447	1946
AA-10221-2	Madisonville	maize	295 ± 50	1639	1	1517	1654
					2	1469	1797
Beta-45674	Madisonville	charcoal	290 ± 45	1640	1	1520	1654
					2	1479	1796
AA-10220-2B	Madisonville	maize	265 ± 45	1647	1	1530	1662
					2	1491	1946
Beta-51845	Madisonville	charcoal	170 ± 50	1676,1764,1770, 1775,1802,1939, 1946	1	1662	1949
					2	1645	1952
DIC-2788	Man	charcoal	1140 ± 55	894,925,935	1	783	981
					2	731	1017
DIC-2841	Man	charcoal	390 ± 70	1476	1	1438	1631
					2	1411	1652
UGa-1523	McJunkin	charred wood	1325 ± 55	679	1	657	768
					2	623	800
UGa-1525	McJunkin	charred wood	660 ± 95	1299,1375	1	1277	1402
					2	1211	1437
UGa-1524	McJunkin	charred wood	570 ± 65	1334,1336,1400	1	1303	1424
					2	1289	1443
Beta-62353	McJunkin	charcoal	380 ± 50	1481	1	1444	1627
					2	1432	1642
M-2201	McKees Rocks	charcoal	620 ± 100	1315,1354,1387	1	1284	1416
					2	1220	1449
RL-1198	Miller	--	850 ± 110	1212	1	1033	1281
					2	984	1385
Beta-15821	Mon City	charcoal	530 ± 70	1412	1	1327	1439
					2	1297	1478
Beta-15819	Mon City	charred wood	420 ± 60	1448	1	1433	1609
					2	1408	1637
Beta-15822	Mon City	charcoal	410 ± 60	1452	1	1436	1616
					2	1411	1640
Beta-15820	Mon City	charred wood	330 ± 50	1522,1573,1627	1	1480	1642
					2	1444	1659
M-1835	Mt. Carbon	charcoal	1130 ± 120	897,922,942	1	735	1020
					2	659	1162
M-1834	Mt. Carbon	charcoal	880 ± 100	1163,1173,1180	1	1024	1263
					2	981	1296
Beta-14987	Muir	--	1010 ± 80	1020	1	979	1155
					2	887	1213
Beta-14991	Muir	--	1010 ± 60	1020	1	984	1148
					2	896	1162

Table 28 (continued).

Lab code	Location	Material Dated[4]	^{14}C age ± 1 sd	Intercept(s)	σ	cal AD/BC[5] max	min
Beta-14988	Muir	--	980 ± 60	1025	1	1000	1157
					2	904	1210
Beta-14989	Muir	--	890 ± 70	1161	1	1033	1221
					2	1003	1279
Beta-14990	Muir	charred wood	790 ± 60	1259	1	1211	1283
					2	1070	1298
Beta-13296	Muir	charcoal	780 ± 50	1263	1	1218	1283
					2	1163	1296
DIC-2196	Newtown Firehouse	human bone	1000 ± 60	1021	1	990	1152
					2	898	1185
OWU-92a	O. C. Voss Md	--	970 ± 79	1029	1	997	1161
					2	897	1240
OWU-229b	O. C. Voss Village	--	1040 ± 215	1000	1	726	1220
					2	602	1390
M-1875	O. C. Voss Village	--	1030 ± 120	1004,1008,1017	1	892	1158
					2	695	1260
M-1882	O. C. Voss Village	--	880 ± 100	1163,1173,1180	1	1024	1263
					2	981	1296
M-1881	O. C. Voss Village	--	830 ± 100	1218	1	1043	1282
					2	1003	1385
OWU-243b	O. C. Voss Village	--	815 ± 220	1222	1	1002	1394
					2	726	1484
M-1873	O. C. Voss Village	--	780 ± 100	1263	1	1163	1296
					2	1024	1398
M-1870	O. C. Voss Village	--	720 ± 100	1284	1	1221	1388
					2	1059	1417
OWU-244	O. C. Voss Village	--	675 ± 90	1297	1	1275	1397
					2	1193	1429
M-1872	O. C. Voss Village	--	575 ± 100	1333,1338,1399	1	1296	1436
					2	1264	1484
M-1871	O. C. Voss Village	--	550 ± 100	1406	1	1301	1441
					2	1278	1616
M-1879	O. C. Voss Village	--	540 ± 100	1409	1	1302	1443
					2	1280	1622
M-1887	O. C. Voss Village	--	520 ± 100	1416	1	1313	1449
					2	1284	1631
OWU-245	O. C. Voss Village	--	517 ± 110	1417	1	1304	1454
					2	1280	1638
M-1884	O. C. Voss Village	--	470 ± 150	1437	1	1314	1631
					2	1269	1946
M-1883	O. C. Voss Village	--	470 ± 100	1437	1	1334	1486
					2	1297	1645
M-1876	O. C. Voss Village	--	450 ± 100	1441	1	1405	1616
					2	1300	1652
OWU-246	O. C. Voss Village	--	387 ± 158	1478	1	1407	1659
					2	1289	1951

Table 28 (continued).

Lab code	Location	Material Dated[4]	^{14}C age ± 1 sd	Intercept(s)	σ	cal AD/BC[5] max	min
ETH-4500	O. C. Voss Village	charred wood	380 ± 80	1481	1	1438	1637
					2	1408	1662
DIC-888	Oglesby-Harris	charcoal	1170 ± 95	887	1	721	983
					2	661	1025
DIC-1034	Oglesby-Harris	human bone	870 ± 80	1165,1166,1188	1	1037	1260
					2	1003	1288
GAK-6227	Ohioview	--	2470 ± 120	-757,-695,-541	1	-796	-400
					2	-833	-233
I-8704	Philo II	charcoal	1125 ± 80	898,921,945,946, 955	1	781	999
					2	691	1032
I-7868	Philo II	--	890 ± 80	1161	1	1028	1240
					2	996	1283
I-14101	Philo II	--	880 ± 80	1163,1173,1180	1	1033	1256
					2	1000	1285
I-14273	Philo II	--	850 ± 90	1212	1	1040	1277
					2	1003	1298
I-14962	Philo II	--	820 ± 80	1221	1	1160	1281
					2	1024	1376
I-7759	Philo II	--	730 ± 80	1282	1	1223	1379
					2	1161	1401
I-7951	Philo II	--	710 ± 80	1287	1	1259	1385
					2	1165	1407
I-8237	Philo II	--	690 ± 80	1293	1	1269	1390
					2	1211	1413
I-14515	Philo II	--	580 ± 80	1332,1340,1398	1	1299	1426
					2	1280	1449
Beta-44974	Portman	charcoal	1060 ± 70	991	1	896	1023
					2	782	1157
Beta-57298	Portman	--	560 ± 50	1403	1	1322	1422
					2	1298	1439
UGa-1643	Portman	charcoal	530 ± 90	1412	1	1313	1443
					2	1286	1616
--	Pyles	burned & unburned bone	1590 ± 120	433	1	265	603
					2	179	664
GX-1742	Raven Rocks	charcoal	1090 ± 100	979	1	784	1023
					2	690	1162
I-9227	Richards	--	690 ± 80	1293	1	1269	1390
					2	1211	1413
I-9140	Richards	charred wood	690 ± 80	1293	1	1269	1390
					2	1211	1413
TX-2345	Richards	charred wood	680 ± 50	1296	1	1282	1385
					2	1262	1399
TX-2344	Richards	--	660 ± 60	1299,1375	1	1284	1393
					2	1262	1410
TX-2346	Richards	--	600 ± 70	1327,1346,1393	1	1297	1413
					2	1279	1439
OWU-225	Riker	--	445 ± 60	1442	1	1422	1480
					2	1335	1629

Table 28 (continued).

Lab code	Location	Material Dated[4]	^{14}C age ± 1 sd	Intercept(s)	σ	cal AD/BC[5] max	min
OWU-175	Riker	--	390 ± 170	1476	1	1403	1662
					2	1282	1952
UGa-553	Rogers RS	uncharred nutshell	1485 ± 55	599	1	537	641
					2	431	660
UGa-552a	Rogers RS	uncharred nutshell	1470 ± 65	602	1	539	650
					2	429	670
UGa-552b	Rogers RS	uncharred nutshell	1415 ± 60	644	1	601	663
					2	538	756
UGa-749	Rogers RS	uncharred nutshell	1345 ± 60	664	1	648	762
					2	602	779
UGa-750	Rogers RS	uncharred nutshell	1245 ± 60	776	1	687	883
					2	660	957
RL-1049	Roseberry Farm	charred wood, 1a	940 ± 110	1040,1100,1116, 1141,1151	1	997	1218
					2	889	1285
UGa-2607	Roseberry Farm	charred wood, 1b	870 ± 75	1165,1166,1188	1	1038	1258
					2	1018	1285
UGa-2606	Roseberry Farm	charred wood, 2a	830 ± 160	1218	1	1023	1297
					2	892	1422
RL-1051	Roseberry Farm	bone, 3a	680 ± 100	1296	1	1263	1398
					2	1163	1435
RL-1050	Roseberry Farm	charred wood, 2b	500 ± 100	1426	1	1327	1469
					2	1289	1637
UGa-2608	Roseberry Farm	bone, 3b	360 ± 65	1491,1603,1609	1	1446	1639
					2	1428	1659
GAK-3727	Ryan	charred wood	1260 ± 80	723,740,771	1	665	886
					2	642	977
GAK-3728	Ryan	charred wood	1180 ± 80	885	1	723	977
					2	665	1019
--	Ryan	human bone	980 ± 80	1025	1	990	1160
					2	894	1221
GAK-3729	Ryan	charred wood	830 ± 80	1218	1	1070	1279
					2	1023	1298
Beta-46466	Saddle	--	920 ± 60	1061,1086,1123, 1138,1156	1	1024	1209
					2	999	1257
Beta-46469	Saddle	--	900 ± 60	1160	1	1033	1216
					2	1018	1264
Beta-48979	Saddle	--	830 ± 60	1218	1	1161	1275
					2	1036	1288
Beta-48980	Saddle	--	780 ± 60	1263	1	1215	1284
					2	1159	1376
Beta-46470	Saddle	--	590 ± 70	1329,1343,1395	1	1299	1417
					2	1281	1441
Beta-46468	Saddle	--	590 ± 50	1329,1343,1395	1	1302	1410
					2	1292	1432
Beta-46467	Saddle	--	580 ± 70	1332,1340,1398	1	1300	1422
					2	1284	1443
Beta-46465	Saddle	--	550 ± 50	1406	1	1326	1427
					2	1300	1441

Table 28 (continued).

Lab code	Location	Material Dated[4]	^{14}C age ± 1 sd	Intercept(s)	σ	cal AD/BC[5] max	min
UGa-929	Sand Ridge	charred wood	1510 ± 100	544,549,558	1	428	646
					2	264	687
WIS-1792	Sand Ridge	charred wood	1320 ± 70	683	1	656	775
					2	604	886
WIS-1747	Sand Ridge	charred wood	1230 ± 70	778	1	688	890
					2	659	980
UGa-1333	Sand Ridge	charred wood	1135 ± 60	895,924,939	1	783	983
					2	724	1019
WIS-1748	Sand Ridge	charred wood	1080 ± 70	981	1	892	1020
					2	779	1152
Beta-17996	Schomaker	--	675 ± 60	1297	1	1281	1389
					2	1256	1405
Beta-31966	Schomaker	--	673 ± 50	1297	1	1283	1387
					2	1264	1401
Beta-14226	Schomaker	maize	543 ± 60	1408	1	1326	1434
					2	1298	1448
Beta-17994	Schomaker	charred wood	516 ± 60	1418	1	1332	1440
					2	1303	1476
Beta-31965	Schomaker	charred wood	482 ± 50	1433	1	1411	1445
					2	1330	1482
I-0000	Slone	charred wood	464 ± 125	1438	1	1329	1622
					2	1285	1787
Beta-13366	Snag Creek	charred wood	890 ± 80	1161	1	1028	1240
					2	996	1283
Beta-11859	Snag Creek	charred wood	520 ± 70	1416	1	1329	1441
					2	1299	1483
Beta-18184	Snag Creek	charred wood	390 ± 70	1476	1	1438	1631
					2	1411	1652
Beta-11858	Snag Creek	charred wood	360 ± 70	1491,1603,1609	1	1444	1640
					2	1424	1662
UGa-2153	State Line	--	785 ± 60	1261	1	1213	1284
					2	1073	1299
UGa-2154	State Line	--	715 ± 55	1285	1	1268	1376
					2	1219	1392
UGa-2152	State Line	--	695 ± 60	1292	1	1277	1383
					2	1222	1400
Beta-13368	Thompson	charred wood	920 ± 100	1061,1086,1123, 1138,1156	1	1018	1221
					2	899	1285
Beta-13367	Thompson	charred wood	810 ± 60	1224,1231,1239	1	1165	1279
					2	1042	1294
Beta-11852	Thompson	charred wood	490 ± 50	1430	1	1408	1443
					2	1329	1479
Beta-11853	Thompson	charred wood	400 ± 70	1468	1	1436	1627
					2	1408	1649
Beta-11851	Thompson	charred wood	110 ± 60	1700,1723,1814, 1832,1879,1915, 1949	1	1676	1953
					2	1659	1955
DIC-783	Tower	charcoal	600 ± 60	1327,1346,1393	1	1299	1410
					2	1283	1435

Table 28 (continued).

Lab code	Location	Material Dated[4]	^{14}C age ± 1 sd	Intercept(s)	σ	cal AD/BC[5] max	min
UGa-4485	Turpin	charred wood	1775 ± 75	244	1	133	379
					2	76	424
UGa-4484	Turpin	charred wood	1760 ± 120	256,303,317	1	128	418
					2	2	556
WIS-1751	Turpin	charred wood	1460 ± 70	605,610,616	1	540	656
					2	430	686
WIS-1750[1]	Turpin	charred wood	1320 ± 70	683	1	656	775
					2	604	886
UGa-4486	Turpin	charred wood	1155 ± 245	891	1	652	1158
					2	414	1298
WIS-1749[1]	Turpin	charred wood	1140 ± 70	894,925,935	1	781	984
					2	692	1022
UGa-4483	Turpin	charred wood	855 ± 65	1194,1196,1210	1	1060	1260
					2	1023	1284
WIS-1793	Turpin	charred wood	820 ± 70	1221	1	1161	1279
					2	1033	1296
M-907	Turpin	charred wood	675 ± 150	1297	1	1219	1414
					2	1025	1484
DIC-2482	Ufferman	--	1150 ± 105	892	1	725	999
					2	661	1152
DIC-2483	Ufferman	--	700 ± 55	1290	1	1277	1380
					2	1223	1396
--	Varner	human bone	1130 ± 80	897,922,942	1	781	997
					2	690	1030
Beta-42250	Varner	--	170 ± 70	1676,1764,1770, 1775,1802,1939, 1946	1	1656	1950
					2	1530	1954
Beta-15506	Water Plant	--	1450 ± 80	620,634,636	1	540	660
					2	427	759
Beta-15508	Water Plant	--	1450 ± 70	620,634,636	1	542	658
					2	432	688
Beta-15507	Water Plant	--	1330 ± 70	674	1	651	772
					2	601	879
SMU-1973	Water Plant	charred wood	1267 ± 102	721,744,769	1	660	889
					2	601	990
DIC-748	White Rocks	charred wood	1340 ± 60	666	1	651	765
					2	603	780
DIC-890	Wood-73	charred wood	1280 ± 55	693,699,715,749, 764	1	668	779
					2	655	888
DIC-889	Wood-73	charred wood	1000 ± 95	1021	1	977	1159
					2	783	1242
Beta-27283	Woods	charred wood	1440 ± 50	623,628,638	1	583	656
					2	537	672
Beta-27284	Woods	charred wood	1380 ± 60	658	1	622	685
					2	560	772
Beta-22396	Woods	charred wood	1180 ± 80	885	1	723	977
					2	665	1019
Beta-27282	Woods	charred wood & nutshell	1120 ± 60	899,920,958	1	785	992
					2	776	1022

Table 28 (continued).

Lab code	Location	Material Dated[4]	^{14}C age ± 1 sd	Intercept(s)	σ	cal AD/BC[5] max	min
Beta-27281	Woods	charred wood & nutshell	1110 ± 70	902,917,962	1	885	1015
					2	732	1030
Beta-22395	Woods	charred wood & nutshell	1090 ± 130	979	1	779	1034
					2	663	1219
Beta-27285	Woods	charred wood	910 ± 60	1071,1079,1128, 1136,1158	1	1028	1213
					2	1003	1260
SMU-2083	W.S. Cole	*charred wood*	728 ± 154	1283	1	1163	1400
					2	1001	1449
ETH-3926	W.S. Cole	*charred wood*	715 ± 75	1285	1	1259	1382
					2	1189	1402
DIC-2284	W.S. Cole	--	680 ± 55	1296	1	1281	1386
					2	1258	1401
UGa-1912	Wylie	charred wood	710 ± 85	1287	1	1257	1386
					2	1163	1410
SMU-1964	Zencor	charred wood	1437 ± 40	624,626,639	1	600	655
					2	541	664
ETH-3067	Zencor	charred nutshell	1425 ± 90	642	1	543	672
					2	428	776
Beta-4348	Zencor	--	1330 ± 60	674	1	656	768
					2	616	806
Beta-4349	Zencor	--	1200 ± 60	782,790,815,842, 859	1	723	936
					2	678	982
Beta-4350	Zencor	--	1170 ± 50	887	1	779	958
					2	694	985
Beta-4347	Zencor	--	950 ± 50	1037,1143,1148	1	1021	1160
					2	996	1214

[1] Multiple ages and/or error terms have been cited for this sample.
[2] Original determination of 590 ± 100 yrs BP recalculated to normalize for fractionation; isotopic composition of maize estimated at -9.5 ‰.
[3] Reported ^{14}C ages for samples conflict between George (1983b) and Hart and Scarry (1999). Unfortunately, Hart and Scarry report feature numbers rather than laboratory codes for all but their AMS dates, whereas George reports laboratory codes and rarely mentions feature number, so it is not possible to compare all of them directly. Ages reported by George appear to include MASCA corrections and so Hart and Scarry's ages were used here.
[4] Samples coated with preservative are indicated in italics.
[5] Lower (max) and upper (min) endpoints of both 1σ and 2σ age ranges in calendar years A.D./B.C. are presented.

NEWLY ACQUIRED RADIOCARBON DETERMINATIONS

Given the emphasis of this research on dietary change associated with maize farming, establishing the time of death for individuals is particularly crucial.

As the local chronologies were being worked out, it became clear that the ages of some skeletal assemblages were unknown, had been estimated based on unclear associations with other dated or undated materials, or seemed at odds with other information about the deposit. It was necessary to acquire ^{14}C determinations for those assemblages that appeared to be especially critical – in this case, skeletal assemblages that might be Late Woodland in age. Nine assemblages (C. L. Lewis, Childers, Chilton, Enos Holmes Mound, Henderson Mound #2, O. C. Voss Mound, Turpin Stone Mound, Ufferman and W. S. Cole) were pinpointed as particularly crucial and efforts were made to obtain radiocarbon determinations directly from skeletal materials analyzed isotopically here.

Problematic radiocarbon ages on bone are not uncommon and there are many cases in the archaeological literature where inaccurate dates on bone have had major impacts on our conceptions of prehistory. In some cases, the "bad" ages were determined using the mineral (bioapatite) fraction, but there have been cases of "bad" ages on the organic, proteinaceous (collagen) fraction of bone, as well (e.g., Stafford et al. 1990, 1991). The primary source of problems for radiocarbon dates obtained from bone protein is the incorporation of exogenous carbonous materials that differ from the bone in ^{14}C content. Most frequently, contamination is from younger humates that serve to decrease the apparent age of the dated material. Indeed, cases where contamination has increased the apparent age of sample are rare. The impact of younger contamination is greater for older samples (Hedges and Law 1989; Hedges and van Klinken 1992) because an equal amount of contamination will contribute an increasingly greater proportion of ^{14}C as the amount of indigenous ^{14}C decreases through radioactive decay with sample age. Simply because a measurable amount of organic material was obtained from bone does not mean that the date obtained necessarily bears any relationship to the time when that bone ceased biological exchange with the carbon reservoir.

Several indicators have been identified which allow evaluation of the relative purity of the bone organic material. I employed some of these techniques to establish the chemical integrity of bone protein extracted for the dietary analysis and the results are detailed in Chapter 5 and Appendices D and F. The skeletal samples analyzed in this study were well-preserved and that the protein extracted from these bones was consistent with expectations derived from analyses of modern bones. This screening all but eliminates the dating problems unique to bone.

Nine samples were submitted to the Center for Accelerator Mass Spectrometry, Lawrence Livermore National Laboratory, for AMS determinations; they are identified by the CAMS- designation in Table 29. One sample was submitted to the Quaternary Isotope Laboratory, University of Washington, for a high precision, conventional determination; it is identified by the QL- designation.

Table 29. Newly-acquired radiocarbon determinations. Years B.C. are negative values. All determinations were corrected for isotopic fractionation.

Lab code	Location	Material Dated	^{14}C age ± 1 sd	Intercept(s)	σ	cal AD/BC[1] max	min
CAMS-22358	C. L. Lewis	human bone	2240 ± 60	-360,-273,-260	1	-390	-202
					2	-402	-124
QL-4932	Childers	human bone	995 ± 34	1022	1	1003	1034
					2	985	1156
CAMS-24779	Chilton	human bone	1800 ± 60	238	1	131	323
					2	77	391
CAMS-22361	Enos Holmes Mnd	human bone	930 ± 60	1043,1091,1119, 1140,1155	1	1023	1205
					2	996	1244
CAMS-22360	Henderson Mnd 2	human bone	1590 ± 60	433	1	411	540
					2	264	616
CAMS-22362	O. C. Voss Mnd	human bone	780 ± 60	1263	1	1215	1284
					2	1159	1376
CAMS-22913	Turpin	human bone	980 ± 50	1025	1	1003	1155
					2	981	1186
CAMS-22359	Turpin	human bone	1150 ± 60	892	1	781	979
					2	694	1017
CAMS-22364	Ufferman	human bone	3080 ± 40	-1381,-1334, -1321	1	-1408	-1265
					2	-1431	-1218
CAMS-22363	W.S. Cole	human bone	1110 ± 50	902,917,962	1	889	993
					2	780	1020

[1] Lower (max) and upper (min) endpoints of both 1σ and 2σ age ranges in calendar years A.D./B.C. are presented.

STATISTICAL ANALYSIS OF RADIOCARBON DATES

For each locale with multiple radiocarbon determinations, I used the testing feature of CALIB to determine if the dates are representative of one or more sample populations (Table 30). Proper use of χ^2 tests assumes comparability among samples; however, such comparability is unlikely among determinations from different laboratories (Ward and Wilson 1978). I suspect the effect of this lack of comparability in any particular case is most likely going to result in a Type I error, i.e., erroneous rejection of the null hypothesis (of no difference), and thus, the actual significance level is probably somewhat greater than the stated $\alpha = 0.05$. The test also assumes that the underlying distribution of sample ages is normal, but it appears to be robust with respect to deviations from normality. When the null hypothesis (of no difference) was rejected for all dates together from a locale, dates were clustered into groups that could reflect statistically the same population. Violation of the comparability assumption would be particularly egregious if I were going to pool clusters of dates found to reflect the same statistical population to produce a mean radiocarbon age; such an approach is not warranted theoretically or empirically.

Table 30. Results of statistical testing of radiocarbon determinations for locales with multiple dates. The numbers (1 through n) identify which samples are included in each combination, with 1 referring to the earliest date, and n referring to the latest date, listed for that locale.

Locale	Group	T'	χ^2 (.05)	Conclusion
Augusta	All	9.94	5.99	Reject H_o
	1, 2	0.00	3.84	Do not reject H_o
Barkers Bottom	All	369.14	16.90	Reject H_o
	3 – 7	7.37	9.49	Do not reject H_o
	8 – 10	2.59	5.99	Do not reject H_o

Table 30 (continued).

Locale	Group	T'	χ^2 (.05)	Conclusion
Blain	All	32.46	11.10	Reject H_o
	1, 2	0.06	3.84	Do not reject H_o
	3 – 5	5.29	5.99	Do not reject H_o
Bonnie Brook	All	7.95	5.99	Reject H_o
	2, 3	0.24	3.84	Do not reject H_o
Buffalo	All	92.65	5.99	Reject H_o
Bunnell Kame	All	1.20	5.99	Do not reject H_o
Bunola	All	0.00	3.84	Do not reject H_o
Campbell Farm	All	28.32	9.49	Reject H_o
	1, 2	4.45	3.84	Reject H_o
	3 – 5	1.04	5.99	Do not reject H_o
Campbell Island	All	1.12	3.84	Do not reject H_o
Childers	SMU dates	5.72	9.49	Do not reject H_o
	Bone dates (1496 max)	1.85	5.99	Do not reject H_o
	Bone dates (1496 min)	11.78	5.99	Reject H_o
	1496 (min), 1498	0.18	3.84	Do not reject H_o
Cleek-McCabe	All	39.12	5.99	Reject H_o
	2, 3	9.20	3.84	Reject H_o
Drew	All	0.11	5.99	Do not reject H_o
Duvall	All	0.45	3.84	Do not reject H_o
Enos Holmes Mnd	All	1.02	3.84	Do not reject H_o
Fox Farm	All	16.23	7.81	Reject H_o
	2 – 4	4.57	5.99	Do not reject H_o
Gnagey	All	109.56	16.90	Reject H_o
	1 – 9	49.78	15.50	Reject H_o
	1 – 7	9.32	12.60	Do not reject H_o
	8, 9	0.12	3.84	Do not reject H_o
Goolman	All	46.78	7.81	Reject H_o
	2 – 4	1.25	5.99	Do not reject H_o
Graham Village	All	3.37	3.84	Do not reject H_o
Guilfoil	All	0.89	3.84	Do not reject H_o

Table 30 (continued).

Locale	Group	T'	χ^2 (.05)	Conclusion
Hansen	All	19.43	14.10	Reject H_o
	1 – 3	1.51	5.99	Do not reject H_o
	4 – 8	4.25	9.49	Do not reject H_o
Henderson Mnd 2	All	0.01	3.84	Do not reject H_o
Henderson Rocks	All	0.30	5.99	Do not reject H_o
Household	All	2.08	3.84	Do not reject H_o
Howard Baum	All	1.66	5.99	Do not reject H_o
Incinerator	All	29.23	21.00	Reject H_o
	1 – 12	15.25	19.70	Do not reject H_o
Killen	All	1.30	7.81	Do not reject H_o
Larkin	All	2.22	3.84	Do not reject H_o
Leonard Haag	All	94.86	12.60	Reject H_o
	1 – 3	1.44	5.99	Do not reject H_o
	4, 5	3.40	3.84	Do not reject H_o
	6, 7	0.06	3.84	Do not reject H_o
Madisonville	All	194.56	31.40	Reject H_o
	1, 2	0.02	3.84	Do not reject H_o
	3, 4	0.07	3.84	Do not reject H_o
	5 – 9	0.19	9.49	Do not reject H_o
	10 – 20	9.86	19.70	Do not reject H_o
Man	All	67.34	3.84	Reject H_o
McJunkin	All	156.15	7.81	Reject H_o
	2 – 4	9.00	5.99	Reject H_o
	2, 3	0.60	3.84	Do not reject H_o
Mon City	All	5.35	7.81	Do not reject H_o
Mt. Carbon	All	2.53	3.84	Do not reject H_o
Muir	All	15.28	11.10	Reject H_o
	1 – 4	1.95	7.81	Do not reject H_o
	5, 6	0.02	3.84	Do not reject H_o
O.C. Voss Mnd	All	3.55	3.84	Do not reject H_o

Table 30 (continued).

Locale	Group	T'	χ^2 (.05)	Conclusion
O.C. Voss Village	All	50.94	27.60	Reject H_o
	1 – 8	8.06	14.10	Do not reject H_o
	9 – 18	3.90	16.90	Do not reject H_o
	4 – 17	19.64	22.40	Do not reject H_o
Oglesby-Harris	All	5.70	3.84	Reject H_o
Philo II	All	29.68	15.50	Reject H_o
	2-9	12.43	14.10	Do not reject H_o
Portman	All	36.36	5.99	Reject H_o
	2, 3	0.08	3.84	Do not reject H_o
Richards	All	1.11	9.49	Do not reject H_o
Riker	All	0.09	3.84	Do not reject H_o
Rogers Rockshelter	All	10.42	9.49	Reject H_o
	1 – 4	3.19	7.81	Do not reject H_o
Roseberry Farm	All	38.17	11.10	Reject H_o
	All wood dates	11.21	7.81	Reject H_o
	Wood dates 1–3	0.40	5.99	Do not reject H_o
	Bone dates	7.08	3.84	Reject H_o
Ryan	All	17.29	7.81	Reject H_o
	1, 2	0.49	3.84	Do not reject H_o
	1 – 3	6.32	5.99	Reject H_o
	3, 4	1.71	3.84	Do not reject H_o
Saddle	All	47.63	14.10	Reject H_o
	1 – 4	3.33	7.81	Do not reject H_o
	5 – 8	0.36	7.81	Do not reject H_o
Sand Ridge	All	15.89	9.49	Reject H_o
	2, 3	0.79	3.84	Do not reject H_o
	4, 5	0.34	3.84	Do not reject H_o
Schomaker	All	10.57	9.49	Reject H_o
	1, 2	0.00	3.80	Do not reject H_o
	3 – 5	0.58	5.99	Do not reject H_o
Snag Creek	All	29.40	7.81	Reject H_o
	2 – 4	2.84	5.99	Do not reject H_o
State Line	All	1.19	5.99	Do not reject H_o

Table 30 (continued).

Locale	Group	T'	χ^2 (.05)	Conclusion
Thompson	All	86.35	9.49	Reject H_o
	1, 2	0.87	3.84	Do not reject H_o
	3, 4	1.03	3.84	Do not reject H_o
Turpin	All	177.89	18.30	Reject H_o
	1, 2	0.01	3.84	Do not reject H_o
	3, 4	1.86	3.84	Do not reject H_o
	5 – 8	5.76	7.81	Do not reject H_o
	9 – 11	1.20	5.99	Do not reject H_o
Varner	All	79.88	3.84	Reject H_o
Wood-73	All	6.30	3.84	Reject H_o
Woods	All	55.49	12.60	Reject H_o
	1, 2	0.54	3.84	Do not reject H_o
	3 – 6	0.58	7.81	Do not reject H_o
Ufferman	All	1192.78	5.99	Reject H_o
	2, 3	14.00	3.84	Reject H_o
W.S. Cole	All	37.77	7.81	Reject H_o
	2 – 4	0.18	5.99	Do not reject H_o
WaterPlant	All	3.34	7.81	Do not reject H_o
Zencor	All	60.71	11.10	Reject H_o
	1 – 3	2.01	5.99	Do not reject H_o
	4, 5	0.14	3.84	Do not reject H_o

THERMOLUMINESCENCE DATES

Occupations at several locales in the region have been dated using thermoluminescence and they are listed Table 31. Although thermoluminescence dates can provide accurate estimates of the number and timing of occupations at a locale, they provide only indirect evidence as to the age of human skeletal or subsistence remains there. Thus, TL dates are relevant to this research only to the extent that the ages of skeletal and/or subsistence remains are not directly known and the timing of occupation(s) must suffice.

Table 31. Published thermoluminescence dates, material dated, and status. Years B.C. are indicated by negative values.

Lab[1]	Sample #	Locale	Material[2]	Age BC/AD	σ	Status[4]
MO	85-5-AU25	Augusta	Sandstone	-1260	330	X
MO	82-4-9	DeVary	Chert	1530	50	
MO	82-4-11	DeVary	Chert	1530	80	
MO	82-4-10	DeVary	Chert	1560	50	
MO	82-4-6A	DeVary	Quartz geode	1630	50	
MO	82-4-7	DeVary	Dolomite	1650	50	
MO	85-5-FG20	Fox Farm	Limestone	> -41,000		X
MO	85-5-FF60	Fox Farm	Limestone	1035	40	X
MO	85-5-FF76	Fox Farm	Burned Clay	1375	40	
MO	82-4-18	Goolman	Chert	1400	60	
MO	82-4-21	Goolman	Chert	1450	55	
MO	82-4-25	Goolman	Dolomite	1450	60	
MO	82-4-20	Goolman	Chert	1550[3]	50	
MO	82-4-22	Goolman	Chert	1600	40	
AA	Alpha-2625	Muir	LS sherd	1450	60	X
AA	Alpha-2626	Muir	LS sherd	1570	50	X
--	--	Pyles	Burned point	1000	260	X
--	--	Pyles	Burned point	1100	230	X
MO	85-5-SN13	Snag Creek	Sandstone	-800	135	X
MO	85-5-SN13	Snag Creek	Sandstone	-550	170	X
MO	85-5-T47	Thompson	Sandstone	850	60	X
MO	85-5-T173	Thompson	Sandstone	1090	80	
MO	85-5-T180	Thompson	Sandstone	1200	40	
MO	85-5-T113	Thompson	Sandstone	1490	40	

[1] AA, Alpha Analytic; MO, Missouri
[2] LS, limestone-tempered.
[3] Also reported as 1500 ± 50
[4] Determination accepted by authors, unless X (rejected by authors).

One of the advantages of TL dating is that the suitability of the sample can often be evaluated by the very laboratory procedures that produce the date. If samples do not behave in predictable ways, then there is reason to suspect that the date will not be accurate. There are five basic problems (Feathers 1997)

that could be involved: (1) the material is not suitably dosimetric (i.e., a luminescence signal does not accumulate with exposure to radiation); (2) the radiation source may be inadequate or too variable; (3) the material was not completely zeroed during the heating event; (4) the material's traps are saturated (i.e., additional exposure to radiation does not increase the luminescence signal); or (5) the luminescence signal is not stable (i.e., some traps are emptied at ambient temperatures). In addition, problems measuring the amount of radiation responsible for the luminescence signal and/or estimating the dose rate will impact the precision and accuracy of the date produced (Feather 1997).

As Table 31 indicates in the "status" column, several TL dates have been rejected by researchers as unacceptable. They were rejected because, in comparisons with ^{14}C dates and/or artifactual evidence regarding the age of the occupation, they were deemed to be too old or too recent. Beyond that, little justification is provided as to *why* the dates might be inaccurate. Presumably dates that are too old should have different problems from those that are too young. In no case does a single locale have dates that are both too old and too young.

Laboratory difficulties were reported only for the rejected TL dates from Muir. Those problems (unusual glow curves and unusually high concentrations of uranium and thorium [Turnbow and Sharp 1988]) may account for dates there that are too recent. The too-recent dates from Pyles were suggested to reflect exposure to a heating event following the Late Woodland occupation there (Railey 1984). The presence of six Madison-type points, typically associated with Late Prehistoric cultures in the area, seems to support a later, albeit minor, use of the locale.

Accounting for most of the TL dates that seem to be too old is also problematic. The Fox Farm date in excess of 41,000 years B.C. is clearly not an accurate indicator of the occupation age there. Researchers speculate that the specimen of burned limestone was not completely zeroed in the heating event or

that there was some form of contamination (Turnbow 1992). No reasons are given to support the rejection of the remaining TL dates, nor are sufficient data provided about the samples and/or their luminescence signals by which the accuracy of the dates could be evaluated independently. Lacking information to the contrary, the judgments of the researchers involved must be accepted here.

APPENDIX B: SUBSISTENCE AND SETTLEMENT DATA

COMPARABILITY AMONG FAUNAL AND BOTANICAL ASSEMBLAGES

FAUNAL PRESERVATION

Chemical conditions of the post-depositional sedimentary matrix influence the composition of archaeofaunal assemblages (Lyman 1994). Accordingly, it is important to evaluate the degree to which assemblages from different depositional contexts have been impacted by the post-depositional environment. Three kinds of data available in the published literature were used to establish four preservation classes (Table 32) that allow assessment of the relative degree of comparability in preservation among the faunal assemblages.

The condition of faunal remains, when noted, provides the most direct information about the state of preservation. Human burials (including especially children and infants) are less useful than faunal remains because burials are often located in circumstances different from the midden deposits where faunal remains are generally deposited (e.g., burial pits are dug into wet, acidic, alluvial soils without benefit of the neutralizing effects of midden accumulation); thus, Mills (1902) remarked that infant burials situated in ash were perfectly preserved, while infants buried in the local soil were so poorly preserved that no bones could be recovered. That infants and, to a lesser extent, children have been recovered is informative because their remains are less densely mineralized than adults and are more sensitive to dissolution by inhospitable soils (Gordon and Buikstra 1981). Similarly, because they are chemically less soluble and have less surface area, a high proportion of teeth relative to bone may indicate poor preservation conditions.

Although soil characteristics such as pH and soil texture (the latter as a correlate of soil moisture capacity [Birkeland 1984]) are consistently recognized as influencing bone preservation (e.g., Gordon and Buikstra 1981; Hare 1980; White

and Hannus 1983), most excavation reports do not include that information. When pH and soil texture data are unavailable in site reports, Bureau of Soils and Soil Conservation Service publications are used, with preference given to those which describe soils prior to long-term intensive liming or fertilizing. This information is only generally useful because as noted above, while soil conditions are important factors, characteristics of the specific deposit can be more influential on bone preservation (Greenlee and Dunnell 1993; Mills 1902; Nale 1963).

The degree to which calcareous tempers are leached or intact can provide information about the relative acidity of the archaeological deposit (Dunnell 1972). In many cases, no mention is made in the text of the condition of the tempering agents; however accompanying photographs often show intact temper particles or alternatively, voids left by their dissolution.

Table 32. Data relevant to assessing preservation of faunal assemblages.

Assemblage	Physical Condition	Soil pH[1]	Soil Texture[2]	Temper Condition[3]
Baum	Excellent	W Acid – Neu[a]	GrL – L[a]	+ Sh[b]
Blain	Excellent	W Acid – Neu[a]	FSaL – SiL[a]	+ Ls, Sh
Buffalo	Excellent	Neu[a]	SiL[a]	+ Sh[b]
Campbell Island	Excellent	Neu – Alk[a]	GrL[a]	+ Sh[b]
Chesser	Excellent	nd	Sa	+ Ls, Sh[b]
Duvall	Excellent	Neu	CL	+ Sh[b]
Barkers Bottom	Excellent	W Acid	FSaL	+ Sh[b]
Feurt	Excellent	Acid – Neu[a]	SiL[a]	+ Sh[b]
Fox Farm	Excellent	Neu – Alk[a]	SiL – SiCL[a]	+ Ls, Sh[b]
Gartner	Excellent	W Acid[a]	SiL[a]	+ Sh[b]
Incinerator	Excellent	Neu – W Alk	SiL[a]	nd
Madisonville	Excellent	Acid[a]	SiL[a]	+ Sh[b]
Peters Cave	Excellent	nd	nd	nd
Philo II	Excellent	W Acid – Neu[a]	FSaL[a]	nd
Raven Rocks	Excellent	nd	Sa	+ Ls, Sh
Richards	Excellent	W Acid – Neu[a]	FSaL[a]	– Sh[b]

Table 32 (continued).

Assemblage	Physical Condition	Soil pH[1]	Soil Texture[2]	Temper Condition[3]
Scarem	Excellent	Acid[a]	SiL[a]	+ Sh[b]
Schomaker	Excellent	W Acid – W Alk[a]	SaL[a]	+ Sh[b]
Tower	Excellent	Acid[a]	L[a]	+ Ls, Sh[b]
White Rocks	Excellent	nd	Sa	+ Sh[b]
Wise Rockshelter	Excellent	nd	Sa	+ Ls[b]
Anderson	Good	W Acid – W Alk[a]	FSaL[a]	+ Sh[b]
Augusta	Good	nd	SiL – CL	– Ls + Sh[b]
Bonnie Brook	Good	S Acid[a]	SiL[a]	– Sh[b]
Boyle	Good	Acid[a]	SiL[a]	– Ls + Sh
Carroll-Oregonia Rd.	Good	W Acid[a]	SiL – CL[a]	+ Sh[b]
Gnagey	Good	W Acid	SiL[a]	+ Ls
Guilfoil	Good	Acid – W Acid[a]	SiL – SiCL[a]	+ Ls, Sh[b]
Henderson Rocks	Good	W Acid[a]	SiL[a]	+ Ls – Sh
Hobson	Good	nd	nd	+ Sh[b]
Johnston	Good	W Acid – W Alk[a]	SiL[a]	– Ls + Sh
Killen	Good	W Acid – W Alk	SiL[a]	+ Sh
McKees Rocks	Good	Acid[a]	SiL[a]	nd
Miller	Good	W Acid	FSaL	+ Sh[b]
Mon City	Good	nd	nd	+ Sh
Mt. Carbon	Good	Neu[a]	FSaL[a]	+ Sh[b]
Muir	Good	Neu – Alk[a]	SiL[a]	30% Ls – Sh
Ryan	Good	Neu – W Alk[a]	SiCL[a]	+ Ls, Sh
Slone	Good	Acid[a]	SaCL[a]	+ Sh[b]
Snag Creek	Good	nd	SaL – SiL	– Ls + Sh[b]
Thompson	Good	Acid – W Alk[a]	SiL[a]	– Ls + Sh[b]
Turpin	Good	W Acid[a]	SiL[a]	+ Sh[b]
Varner	Good	W Acid – Neu[a]	SaL – SiL[a]	nd
Dameron	Fair	W Acid[a]	Sa – SaL[a]	– Css, Sh
Drew	Fair	S Acid[a]	SiL[a]	nd
Gabriel	Fair	nd	nd	– Ls + Sh[b]
Graham	Fair	Acid – Neu[a]	SiL[a]	– Sh

Table 32 (continued).

Assemblage	Physical Condition	Soil pH[1]	Soil Texture[2]	Temper Condition[3]
Leonard Haag	Fair	Acid[a]	SiL[a]	nd
Pyles	Fair	nd	SiL	+ Ls
Riker	Fair	nd	nd	nd
Childers	Poor	Acid	L – SCL	36% – Ls
Goolman	Poor	Neu – W Alk	SiC – SiCL	– Ls, Sh
Hansen	Poor	Acid – Neu	SiL	– Ls
Wylie	Poor	S Acid	SiL[a]	– Ls, Sh
Portman	Poor	S Acid	SiL	nd

[1] W = Weakly; S = Strongly; Neu = Neutral; Alk = Alkaline; nd = no data
[2] F = Fine; Gr = Gravelly; Sa = Sandy; Si = Silty; C = Clay; L = Loam; nd = no data
[3] + Sh = Shell intact; + Ls = Limestone intact; + Ls, Sh = Limestone and Shell intact; – Sh = Shell leached; – Ls = Limestone leached; – Ls, Sh = Limestone and Shell leached; – Ls + Sh = Limestone leached and Shell intact; CSS = Calcareous sandstone; nd = no data
[a] source of information = soil survey
[b] assessed through examination of photographs

Implications of the Preservation Classification

While this evaluation is crude, it minimizes the impact of differential preservation on this analysis in the absence of more direct information (e.g., weathering profiles [Behrensmeyer 1978]). That the first parameter, physical description, seems to provide an effective means of partitioning the faunal assemblages into four groups of potentially comparable preservation is clear in Figure 168. There is a general relationship between the physical condition of faunal assemblages and the characteristics of the deposits from which they come. For each faunal variable analyzed, variation across these different classes is examined to eliminate patterning structured by preservation conditions.

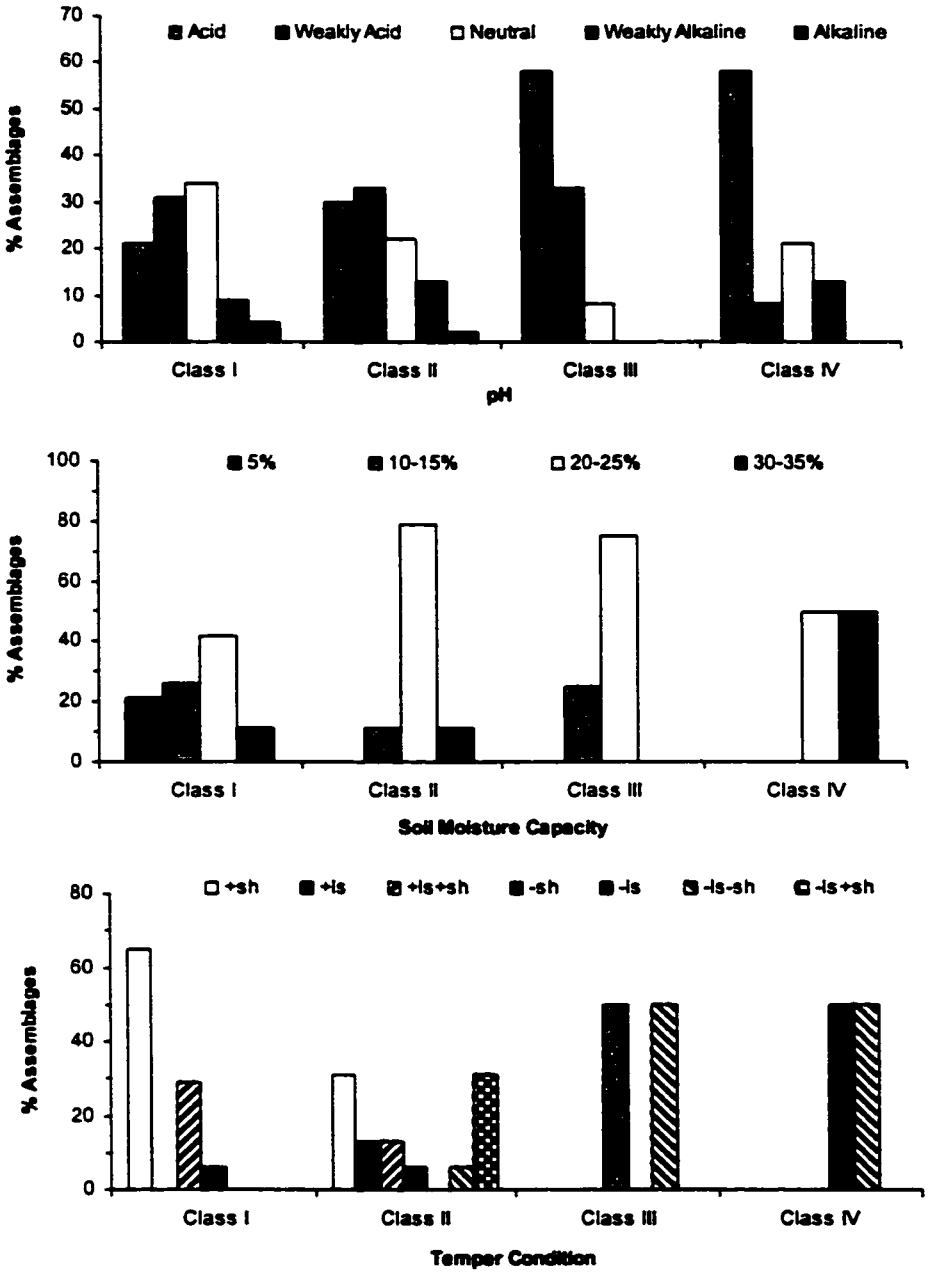


Figure 168. **Distribution of faunal preservation classes with respect to deposit characteristics.** Class I, excellent; Class II, good; Class III, fair; Class IV, poor.

ASSEMBLAGE RECOVERY

Because excavations in the Ohio River valley have been conducted over a 100-year time span, there is considerable variation in the recovery techniques represented. It is well documented (e.g., Grayson 1984; Shaffer and Sanchez 1992; Wagner 1988a) that recovery techniques may bias assemblages. Use of screens, different screen mesh sizes, and dry-screen, wet-screen, or flotation technology can result in differential recovery of particular size classes of materials; since the size distributions of fauna and flora in nature are structured, this may result in the differential recovery and representation of particular taxa. For these reasons, assemblages are identified according to the dominant collection technique used (Table 33). In those reports where discussion regarding recovery techniques is lacking, it is presumed that recovery was a result of gross inspection; while this may not be the case, it is better to err conservatively. For several faunal assemblages, flotation was noted as part of the recovery strategy, but it contributed an unknown amount of identifiable bone to most of them.

Table 33. Recovery techniques used to acquire archaeo-faunal and -botanical assemblages.

Assemblage	Faunal Remains[1]	Botanical Remains[1]
Anderson	Gross Inspection	Gross Inspection
Augusta	¼" Screen	Flotation
Baldwin	--	Gross Inspection
Barker's Bottom	¼" Screen	Flotation
Baum	Gross Inspection	Gross Inspection
Blain	Gross Inspection	Gross Insp./Flotation
Bonnie Brook	Gross Inspection	Flotation
Boyle	Gross Inspection	--
Buffalo	Gross Inspection	--
Campbell Island	Gross Inspection	Gross Inspection
Carroll-Oregonia Rd.	Gross Inspection	--
Chesser Cave	Gross Inspection	--

Table 33 (continued).

Assemblage	Faunal Remains[1]	Botanical Remains[1]
Childers	¼" Screen/Flotation	Flotation
Cramer	--	Gross Inspection
Dameron	1/8" Screen	--
DeVary	--	Flotation
Drew	Gross Inspection	Gross Inspection
Duvall	¼" Screen	--
Feurt	Gross Inspection	Gross Inspection
Fox Farm	Gross Insp/¼" Screen	Gross Insp./Flotation
Gabriel	Gross Inspection	Gross Inspection
Gartner	Gross Inspection	Gross Inspection
Gnagey	Gross Inspection	Gross Inspection
Goolman	½" Screen	Flotation
Graham	Gross Inspection	Gross Inspection
Guilfoil	¼" Screen	Flotation
Hansen	¼" Screen	Flotation
Haystack Rockshelter	--	1 mm Screen
Henderson Rocks	¼" Screen	--
Hobson	Gross Inspection	--
Howard Baum	--	Flotation
Incinerator	¼" Screen	Flotation
Johnston	Gross Inspection	--
Killen	¼" Screen	--
Laughlin	--	Flotation
Leonard Haag	½" Screen	Flotation
Madisonville	Gross Inspection	Gross Inspection
McKees Rocks	Gross Inspection	Gross Inspection
Miller	Gross Insp./Screen	--
Mon City	¼" Screen/Flotation	Flotation
Mount Carbon	Gross Inspection	--
Muir	¼" Screen	Flotation
Peters Cave	Gross Inspection	--

Table 33 (continued).

Assemblage	Faunal Remains[1]	Botanical Remains[1]
Philo II	Gross Inspection	Flotation
Portman	Gross Insp./ ¼" Screen	Gross Insp./ ¼" Screen
Pyles	Gross Inspection	--
Raven Rocks	Gross Inspection	Gross Insp./Flotation
Richards	Gross Inspection	Flotation
Riker	Gross Inspection	--
Rogers Rockshelter	--	¼" Screen/Flotation
Roseberry Farm	--	Gross Inspection
Ryan	Gross Inspection	Flotation
Sand Ridge	--	Flotation
Scarem	Screen	--
Schomaker	¼" Screen	Flotation
Slone	Gross Inspection	--
Snag Creek	¼" Screen	Flotation
State Line	--	Flotation
Thompson	¼" Screen	Flotation
Tower	¼" Screen	--
Turpin	¼" Screen	Gross Inspection
Varner	Screen	--
Waterplant	--	Flotation
White Rocks	Gross Inspection	--
Wise Rockshelter	Screen	--
Woods	--	Flotation
Wylie	Screen	--
Zencor	--	Flotation

[1] Published assemblage lacking is indicated as --.

The optimal approach to evaluating the potential of size bias would consider histograms showing the size distribution of the specimens in each assemblage, but that kind of information is not available. As shown in Table 34, avian and mammalian taxa have been subdivided into four size classes on the basis

of body size (body length and weight, respectively). The limits of the four size classes were chosen to minimize overlap among taxa. Reptiles, fish and amphibians, which can vary greatly in size, were assigned to a fifth class. Table 35 lists, for each size class, the taxa reported in the faunal assemblages considered here.

Among locales where multiple assemblages were recovered using varying techniques, substantial differences in the frequency distribution of size classes have been documented (Greenlee 2002). It has also been shown that one effective way to minimize the impact of different collection techniques, thereby

Table 34. Size classification for faunal taxa. Body weight data come from Chapman and Feldhamer (1982), Hamilton and Whitaker (1979), Hoffmeister (1989) and Rue (1981). Bird total length data come from Collins (1959) and Terres (1980).

Size Class	Description	Mammal Weight	Bird Total Length
1	Very Small	$x < 0.5$ kg	$x < 6$"
2	Small	0.5 kg $\leq x < 2$ kg	6" $\leq x < 15$"
3	Medium	2 kg $\leq x < 30$ kg	15" $\leq x < 25$"
4	Large	30 kg $\leq x$	25" $\leq x$
5	Variable: Fish, Reptiles and Amphibians		

increasing the comparability of assemblages, is to eliminate from consideration those taxa that are most affected by collection technique. Removing Class 1 (very small) and Class 5 (variable) taxa significantly improves comparability among assemblages (Greenlee 2002). Consequently, unless specifically stated otherwise, these two classes are considered to provide nominal level data only. In addition, for each faunal variable analyzed, variation across these different size classes is examined to eliminate patterning that could be structured by collection strategy.

Table 35. List of faunal taxa for the size classification.

Size Class 1

Blarina brevicauda
Cricetidae spp.
Eptesicus fuscus
Eutamias spp.
Glaucomys spp.
Glaucomys volans
Microtus (Pitymys) pinetorium
Microtus pennsylvanicus
Microtus spp.
Mustela frenata
Mustela nivalis
Myotis spp.
Neotoma floridana
Oryzomys palustris
Parascalops breweri
Peromyscus leucopus
Peromyscus maniculatus
Peromyscus spp.
Rodentia spp.
Scalopus aquaticus
Scalopus/Parascalops spp.
Sorex spp.
Spermophilus (Citellus) tridecemlineatus
Synaptomys cooperi
Tamias striatus
Tamiasciurus hudsonicus
Zapus hudsonius

Size Class 2

Martes americana
Mustela vision
Ondatra zibethicus
Sciurus carolinensis
Sciurus niger
Sciurus spp.
Sylvilagus floridanus
Sylvilagus spp.
Accipiter striatus
Bucephala albeola
Chordeiles minor
Coccyzus spp.
Colaptes auratus
Colinus virginianus
Conuropsis carolinensis
Cyanocitta cristata
Falco sparverius
Hirundo rustica (erythrogaster)
Ixobrychus exilis
Megaceryle (Ceryle) alcyon
Melanerpes (Centurus) carolinus
Melanerpes erythrocephalus
Melanerpes spp.
Otus asio
Philohela (Scolopax) minor
Picoides (Dendrocopus) pubescens
Pipilo erythrophthalmus
Podilymbus podiceps
Progne subis
Quiscalus quiscula
Sphyrapicus varius
Sturnella magna
Toxostoma rufum
Tringa (Totanus) flavipes
Turdus migratorius

Size Class 3

Canis familiaris
Canis latrans
Castor canadensis
Didelphis virginana
Erethizon dorsatum
Felis (Lynx) rufus
Lutra canadensis
Marmota monax
Martes pennanti
Mephitis mephitis
Procyon lotor
Taxidea taxus
Urocyon cinereoargenteus
Urocyon spp.
Vulpes spp.
Vulpes vulpes (fulva)
Vulpes/Urocyon spp.
Accipiter cooperi
Aix sponsa
Anas acuta
Anas platyrhynchos
Anas rubripes
Anas spp.
Aythya valisneria
Bonasa spp.
Bonasa umbellus
Bubo virginianus
Buteo jamaicensis
Buteo lineatus
Buteo platypterus
Campephilus principalus
Corvus brachyrhynchos
Dryocopus pileatus
Ectopictes migratorius

Table 35 (continued).

Size Class 3 (continued)

Lophodytes cucullatus
Mergus spp.
Numenius americanus
Oxyura (Erismatura) jamaicensis
Strix varia
Tympanuchus cupido

Size Class 4

Bison bison
Canis lupus
Cervus canadensis (elaphus)
Felis concolor
Odocoileus virginianus
Odocoileus/Cervus spp.
Ursus americanus
Aquila chrysaetos
Ardea herodias
Branta canadensis
Branta/Chen spp.
Cathartes aura
Chen caerulescens
Chen spp.
Coragyps atratus
Corvus corax
Gavia immer
Grus canadensis
Haliaeetus leucocephalus
Meleagris gallopavo
Olor (Cygnus) buccinator
Olor (Cygnus) columbianus
Olor (Cygnus) spp.

Size Class 5

Agkistrodon contortrix
Agkistrodon piscivorus
Agkistrodon spp.
Chelydra serpentina
Chrysemys (Pseudemys) floridana
Chrysemys picta
Chrysemys spp.
Chrysemys/Pseudemys/Graptemys spp.
Clemmys insculpta
Coluber constrictor
Colubridae spp.
Crotalidae spp.
Crotalus horridus
Crotalus spp.
Elaphe obsoleta
Elaphe spp.
Emys/Clemmys/Graptemys spp.
Graptemys geographica
Heterodon platyrhinos
Lampropeltis spp.
Pseudemys (Chrysemys) scripta
Sternotherus odoratus
Terrapene carolina
Terrapene spp.
Thamnophis sirtalis
Trionyx ferox (spiniferus)
Trionyx muticus
Trionyx spp.
Viperiadae spp.
Ambystoma maculatum
Ambystoma spp.
Bufo americanus (terrestris?)
Bufo spp.
Bufo/Rana spp.
Caudata spp.
Cryptobranchus alleganiensis
Natrix spp.
Necturus maculosus
Rana catesbiana
Rana pipiens
Rana spp.
Acipenser fulvescens
Acipenseridae spp.
Anguilla rostrataAplodinotus grunniens
Catostomidae spp.
Catostomus commersoni
Centrarchidae spp.
Cyprinidae spp.
Esox masquinnongy
Hypentelium nigricans
Ictaluridae spp.
Ictalurus punctatus
Ictalurus spp.
Ictiobus cyprinellus
Ictiobus spp.
Lepisosteus spp.*Micropterus* spp.
Moxostoma spp.
Nocomis (Hybopsis) biguttata
Noturus flavus
Noturus spp.
Perca flavescens
Pylodictis olivaris
Scaphirhynchus platorynchus
Semotilus atromaculatus
Serranidae spp.
Stizostedion spp.
Stizostedion vitreum
Stizostedion/Perca

FAUNAL CLASSIFICATION

Two classification systems, as alternatives to the Linnaean taxonomic system, were used in this research. The first, a resource acquisition classification, was developed by Neusius (1986) and the second, a habitat preservation classification, was developed as part of this research. In Tables 36 and 37 below, I list faunal taxa assigned to classes within these classification schemes.

Table 36. List of faunal taxa for the resource acquisition classification.

Waterfowl

Aix sponsa
Anas acuta
Anas platyrhynchos
Anas rubripes
Anas spp.
Ardea herodias
Aythya valisneria
Branta canadensis
Bucephala albeola
Chen caerulescens
Chen spp.
Gavia immer
Grus canadensis
Ixobrychus exilis
Lophodytes cucullatus
Megaceryle (Ceryle) alcyon
Mergus spp.
Olor (Cygnus) buccinator
Olor (Cygnus) columbianus
Olor (Cygnus) spp.
Oxyura (Erismatura) jamaicensis
Podilymbus podiceps

Other Birds

Accipiter cooperi
Accipiter striatus
Aquila chrysaetos
Bonasa spp.
Bonasa umbellus
Bubo virginianus
Buteo jamaicensis
Buteo lineatus
Buteo platypterus
Campephilus principalus
Cathartes aura
Chordeiles minor
Coccyzus spp.
Colaptes auratus
Colinus virginianus
Conuropsis carolinensis
Coragyps atratus
Corvus brachyrhynchos
Corvus corax
Cyanocitta cristata
Dryocopus pileatus
Ectopictes migratorius
Falco sparverius
Haliaeetus leucocephalus
Melanerpes (Centurus) carolinus
Melanerpes erythrocephalus
Melanerpes spp.
Otus asio
Philohela (Scolopax) minor
Picoides (Dendrocopus) pubescens
Pipilo erythrophthalmus
Progne subis
Quiscalus quiscula
Sphyrapicus varius
Strix varia
Tringa (Totanus) flavipes
Toxostoma rufum
Turdus migratorius

Aquatic Mammals

Castor canadensis
Lontra canadensis
Mustela vision
Ondatra zibethicus

Table 36 (continued).

Other Mammals

Bison bison
Canis latrans
Canis lupus
Cervus canadensis (elaphus)
Didelphis virginana
Erethizon dorsatum
Felis (Lynx) rufus
Felis concolor
Marmota monax
Martes americana
Martes pennanti
Mephitis mephitis
Sylvilagus floridanus
Sylvilagus spp.
Taxidea taxus
Urocyon cinereoargenteus
Urocyon spp.
Ursus americanus
Vulpes spp.
Vulpes vulpes (fulva)

Domestic Dog

Canis familiaris

Raccoon

Procyon lotor

Turkey

Meleagris gallopavo

Squirrel

Sciurus spp.
Sciurus niger
Sciurus carolinensis

Table 37. List of faunal taxa for the habitat preference classification.

Birds, Aquatic/Semi-Aquatic

Aix sponsa
Anas acuta
Anas platyrhynchos
Anas rubripes
Anas spp.
Ardea herodias
Aythya valisneria
Branta canadensis
Bucephala albeola
Chen caerulescens
Chen spp.
Gavia immer
Grus canadensis
Haliaeetus leucocephalus
Ixobrychus exilis
Lophodytes cucullatus
Megaceryle (Ceryle) alcyon
Mergus spp.
Numenius americanus
Olor (Cygnus) buccinator
Olor (Cygnus) columbianus
Olor (Cygnus) spp.
Oxyura (Erismatura) jamaicensis
Philohela (Scolopax) minor
Podilymbus podiceps
Tringa (Totanus) flavipes

Birds, Mature Woodlands

Accipiter cooperi
Accipiter striatus
Bubo virginianus
Buteo platypterus
Campephilus principalus
Corvus corax
Dryocopus pileatus
Ectopictes migratorius
Melanerpes (Centurus) carolinus
Strix varia

Table 37 (continued).

Birds, Secondary/Forest Edge

Aquila chrysaetos
Bonasa spp.
Bonasa umbellus
Buteo jamaicensis
Buteo lineatus
Chordeiles minor
Coccyzus spp.
Colaptes auratus
Colinus virginianus
Conuropsis carolinensis
Coragyps atratus
Cyanocitta cristata
Falco sparverius
Melanerpes erythrocephalus
Meleagris gallopavo
Otus asio
Picoides (Dendrocopus) pubescens
Pipilo erythrophthalmus
Quiscalus quiscula
Sphyrapicus varius
Toxostoma rufum
Turdus migratorius

Birds, Prairie/Grassland

Sturnella magna
Tympanuchus cupido

Mammals, Aquatic/Semi Aquatic

Castor canadensis
Lutra canadensis
Mustela vision
Ondatra zibethicus

Mammals, Secondary/Forest Edge

Cervus canadensis (elaphus)
Didelphis virginana
Felis (Lynx) rufus
Felis concolor
Marmota monax
Mephitis mephitis
Odocoileus virginianus
Procyon lotor
Sciurus niger
Sylvilagus floridanus
Sylvilagus spp.
Urocyon cinereoargenteus
Urocyon spp.
Vulpes spp.
Vulpes vulpes (fulva)

Mammals, Prairie/Grassland

Bison bison
Canis latrans
Taxidea taxus

Mammals, Mature Woodland

Erethizon dorsatum
Martes americana
Martes pennanti
Sciurus carolinensis
Ursus americanus

Commensal Animals

Canis familiaris

BOTANICAL DATA

Table 38. Ubiquity data for seeds of the Eastern Agricultural Complex. Presence indicated by +, absence indicated by 0, and no data indicated by --.

Assemblage	n	Chenopodium	Maygrass	Knotweed	Sunflower	Little Barley	Sumpweed
Pyles	1	0	0	0	0	0	0
Haag (LW)	29	+	+	+	0	0	+
Hansen	112	5.10	8.30	4.50	0	0	0
Childers	49	89.80	83.67	28.57	14.29	4.08	36.73
Haystack	--	+	+	0	+	0	+
Waterplant	18	40.00	66.70	40.00	0	0	6.70
Rogers	5	+	+	0	+	0	+
Zencor	23	81.82	90.91	50.00	4.55	0	9.09
Sand Ridge (LW)	--	+	+	+	+	0	+
Woods	31	32.26	16.13	6.45	3.23	0	3.23
Raven Rocks	--	0	0	0	0	0	0
Barkers Bottom	--	0	0	0	0	0	0
Baum	--	0	0	0	0	0	0
Ryan	--	0	0	0	0	0	0
Cramer	--	0	0	0	+	0	0
Muir	50	2.00	0	6.00	8.00	0	0
Gartner	--	0	0	0	0	0	0
Gnagey	23	0	0	9	0	0	0
Thompson	--	0	0	0	0	0	0
Roseberry Farm	--	0	0	0	0	0	0
Drew	--	0	0	0	0	0	0
Blain	5	0	0	0	0	0	0
Graham	--	0	0	0	0	0	0
Philo II	--	0	0	0	0	0	0
Anderson	--	0	0	0	0	0	0
Guilfoil	6	0	0	0	0	0	0
State Line	83	+	0	+	0	0	0
Haag (LP)	6	+	0	+	0	0	+
Incinerator	--	+	0	+	+	+	0
Madisonville (mLP)	1	+	0	0	0	0	0
Sand Ridge (LP)	--	+	+	+	+	0	0
Howard Baum	--	+	0	0	0	0	0
Richards	--	0	0	0	0	0	0
Feurt	--	0	0	0	0	0	0

Table 38 (continued).

Assemblage	n	Chenopodium	Maygrass	Knotweed	Sunflower	Little Barley	Sumpweed
Baldwin	--	0	0	0	0	0	0
Gabriel	--	0	0	0	0	0	0
McKees Rocks	--	0	0	0	0	0	0
Schomaker	8	62.50	25.00	14.30	0	0	0
Portman	3	0	0	0	0	0	0
Bonnie Brook	38	0	0	0	0	0	0
Campbell Island	--	0	0	0	+	0	0
Augusta	--	0	0	0	0	0	0
Fox Farm	--	+	0	+	0	0	0
Snag Creek	--	0	0	+	0	0	0
Mon City	8	37.50	0	37.50	0	0	0
Goolman	11	27.30	0	45.50	0	0	0
Laughlin	--	0	0	0	0	0	0
DeVary	31	10.00	0	10.00	0	0	0
Madisonville (ILP)	9	44.00	0	11.00	22.00	11.00	0

[1] Due to variation in reporting, n may indicate number of features, number of excavation blocks/units or number of flotation samples.

Table 39. Ubiquity data for squash/gourd, maize, beans, fruits and berries, and nuts. Presence indicated by +, absence indicated by 0, and no data indicated by --.

Assemblage	n[1]	Squash	Maize	Beans	Fruits & Berries (Mean Ubiquity)	Nuts (Mean Ubiquity)
Pyles	1	0	0	0	0	+
Haag (LW)	29	31.00	0	0	+	50.85
Hansen	112	0	0	0	4.16	+
Childers	49	81.60	12.24	0	24.49	61.63
Haystack	--	+	0	0	+	+
Water Plant	18	50	0	0	16.68	34.26
Rogers RS	5	+	0	0	+	+
Zencor	23	82.61	0	0	43.18	55.65
Sand Ridge (LW)	--	+	+	0	+	+
Woods	31	7.32	58.54	0	8.06	30.27
Raven Rocks	--	0	0	0	+	+
Barker's Bottom	--	0	+	0	+	+
Baum	--	0	+	+	+	+
Ryan	--	0	+	+	0	+
Cramer	--	+	+	+	+	+
Muir	50	0	96.00	18.00	9.00	88.00

Table 39 (continued).

Assemblage	n[1]	Squash	Maize	Beans	Fruits & Berries (Mean Ubiquity)	Nuts (Mean Ubiquity)
Gartner	--	0	+	+	+	+
Gnagey	23	9.00	96.00	35.00	11.33	--
Thompson	--	+	+	0	+	+
Roseberry Farm	--	0	+	0	0	--
Drew	--	0	+	+	+	+
Blain	5	20.00	+	40.00	+	60.00
Graham	--	0	+	0	0	+
Philo II	--	0	+	+	+	+
Anderson	--	0	+	+	+	+
Guilfoil	6	0	100.00	67.00	44.47	60.02
State Line	83	0	+	+	+	+
Leonard Haag (LP)	6	16.70	100.00	0	+	72.23
Incinerator	--	0	+	+	+	+
Madisonville (mLP)	1	+	+	+	+	+
Sand Ridge (LP)	--	+	+	0	+	+
Howard Baum	--	+	+	0	+	--
Richards	--	0	+	+	+	+
Feurt	--	0	+	+	+	+
Baldwin	--	0	+	+	+	+
Gabriel	--	0	+	+	+	+
Mckees	--	0	+	+	0	+
Schomaker	8	37.50	100.00	0	42.88	62.50
Portman	3	0	33.30	12.10	0	6.10
Bonnie Brook	38	0	8.00	0	3.00	--
Campbell Island	--	0	+	+	+	+
Augusta	--	+	+	0	+	+
Fox Farm	--	+	+	+	+	+
Snag Creek	--	+	+	+	0	+
Mon City	8	0	62.50	25.00	+	--
Goolman	11	0	15.50	0	9.00	34.80
Laughlin	--	0	+	0	0	+
DeVary	31	0	18.20	0	10.00	44.47
Madisonville (lLP)	9	78.00	100.00	44.00	48.50	77.78

[1] Due to variation in reporting, n preferentially indicates number of features, but may indicate number of excavation blocks or samples analyzed.

Table 40. Mean ubiquity of EAC plants, weedy plants and secondary wood taxa. Missing data indicated by --.

Assemblage	EAC Plants (Mean Ubiquity)	Weedy Plants (Mean Ubiquity)	Secondary Wood (Mean Ubiquity)
Hansen	5.97	7.30	22.86
Childers	42.86	32.65	18.38
Water Plant	38.35	11.10	20.53
Zencor	47.27	10.91	16.40
Woods	12.26	12.90	22.45
Muir	5.33	2.00	--
Gnagey	9.00	--	--
Blain	0.00	20.00	--
Guilfoil	0.00	16.70	--
Schomaker	33.93	28.60	--
Mon City	37.50	--	--
Goolman	36.40	27.20	8.40
DeVary	10.00	33.33	9.70
Madisonville (ILP)	22.00	44.40	--

Table 41. Mean ubiquity of seasonal plant resources.

Assemblage	Spring (Mean Ubiquity)	Summer (Mean Ubiquity)	Fall (Mean Ubiquity)
Hansen	12.15	1.70	6.42
Childers	48.98	17.01	47.36
Water Plant	66.70	13.30	32.41
Zencor	90.91	77.27	52.23
Woods	11.29	6.45	20.29
Muir	0.00	2.00	37.50
Gnagey	0.00	26.00	7.33
Blain	0.00	20.00	40.00
Guilfoil	0.00	0.00	54.19
Schomaker	25.00	42.90	57.86
Bonnie Brook	0.00	3.00	0.00
Mon City	0.00	0.00	37.50
Goolman	0.00	0.00	28.14
Madisonville (ILP)	11.00	67.00	68.63
DeVary	0.00	0.00	30.68

Table 42. Number of seed genera and number of seeds identified to genera.

Assemblage	n Genera	n Seeds
Haag LW	11	357
Hansen	25	867
Childers	43	5427
Water Plant	15	402
Haystack	9	122
Zencor	16	1946
Woods	27	667
Barkers	3	5
Muir	11	6506
Thompson	8	984
Blain	8	4775
State Line	11	1758
Guilfoil	6	936
Haag LP	8	129
Madisonville (mLP)	12	941
Schomaker	13	1431
Augusta	5	12
Fox Farm	13	1566
Snag Creek	5	356
Goolman	13	206
Laughlin	2	51
DeVary	13	237
Madisonville (lLP)	24	6219

FAUNAL DATA

Table 43. NISP and richness of vertebrate taxa (excluding size class 1 and class 5 taxa) according to different classification systems.

Assemblage	Vertebrate Genera		Resource Acquisition		Habitat Preference	
	NISP	Classes	NISP	Classes	NISP	Classes
Pyles	110	4	111	4	110	3
Leonard Haag (LW)	1010	19	1032	9	984	7
Hansen	27	3	27	3	27	2
Childers	2415	13	2425	8	2392	5
Chesser	1895	17	1929	7	1894	4
Peters Cave	62	10	64	6	62	4
White Rocks (LW)	1617	13	1601	5	1581	4
Wise RS	259	15	258	8	247	6

Table 43 (continued).

Assemblage	Vertebrate Genera		Resource Acquisition		Habitat Preference	
	NISP	Classes	NISP	Classes	NISP	Classes
Varner	1919	23	1936	8	1837	5
Turpin (LW)	212	9	216	6	210	5
Raven Rocks	2319	24	2303	8	2291	5
Barker's Bottom	550	10	603	7	550	4
White Rocks (LP)	2972	19	2952	9	2886	7
Ryan	305	14	310	8	299	6
Muir	1777	20	2049	8	1777	6
Thompson	1645	17	1775	9	1643	7
Hobson	569	9	654	6	559	4
Gnagey	1850	25	1909	9	1833	8
Mount Carbon	8435	30	8675	9	8415	7
Turpin (LP)	297	13	300	7	285	6
Miller	798	12	869	9	797	6
Drew	1706	29	1966	8	1623	6
Blain	4199	27	4721	9	4100	8
Boyle	728	18	721	7	694	6
Philo II	5572	29	6049	9	5549	7
Graham Village	792	7	811	6	792	4
Guilfoil	562	16	601	7	540	5
Henderson Rocks	1404	18	1546	8	1402	6
Leonard Haag (LP)	148	11	153	7	145	4
Duvall	76	11	69	5	69	4
Scarem	330	16	343	9	330	6
Johnston	770	15	796	8	764	5
Wylie	727	11	734	8	720	6
Killen	265	5	282	5	265	3
Richards	3367	26	3888	9	3357	7
Gabriel	942	9	1186	7	942	4
Tower	1158	17	1308	9	1158	7
McKees Rocks	2753	29	2814	9	2696	7
Dameron	45	6	44	5	44	3
Portman	206	10	206	6	206	4
Bonnie Brook	145	15	161	7	145	4
Carroll-Oregonia Rd.	66	9	67	6	66	4
Augusta	303	9	347	7	303	4
Slone	2235	16	2205	7	2151	5
Fox Farm	901	16	1029	7	897	5
Snag Creek	204	16	223	9	203	7
Riker	1805	18	2017	9	1796	7
Mon City	501	10	579	9	483	6
Goolman	266	4	266	3	266	1
Buffalo	58575	42	61635	9	58504	7

Table 44. Equitability index (J') for vertebrate fauna using different classification systems and the relative frequency (% NISP for the resource acquisition classification) of the deer acquisition class.

Assemblage	Genera J'	Resource J'	Habitat J'	Deer Acquisition
Pyles	0.187	0.206	0.189	93.694
Leonard Haag (LW)	0.383	0.459	0.306	74.322
Hansen	0.382	0.382	0.381	88.889
Childers	0.140	0.168	0.096	93.526
Chesser	0.276	0.363	0.193	82.685
Peters Cave	0.734	0.727	0.388	46.875
White Rocks (LW)	0.166	0.217	0.086	92.942
Wise RS	0.670	0.784	0.331	43.798
Varner	0.508	0.650	0.367	57.696
Turpin (LW)	0.298	0.379	0.166	83.796
Raven Rocks	0.302	0.337	0.220	79.896
Barker's Bottom	0.398	0.519	0.438	69.818
White Rocks (LP)	0.201	0.236	0.163	88.923
Ryan	0.458	0.495	0.329	70.968
Muir	0.318	0.549	0.369	64.422
Thompson	0.313	0.460	0.308	73.239
Hobson	0.381	0.583	0.375	65.596
Gnagey	0.607	0.617	0.514	42.640
Mount Carbon	0.319	0.456	0.369	70.340
Turpin (LP)	0.373	0.461	0.233	77.667
Miller	0.268	0.394	0.273	77.560
Drew	0.395	0.583	0.385	53.764
Blain	0.408	0.574	0.366	58.653
Boyle	0.480	0.571	0.204	60.333
Philo II	0.247	0.428	0.254	75.004
Graham Village	0.286	0.345	0.117	83.724
Guilfoil	0.494	0.651	0.471	60.566
Henderson Rocks	0.263	0.446	0.299	74.515
Leonard Haag (LP)	0.314	0.392	0.198	81.699
Duvall	0.693	0.728	0.454	59.420
Scarem	0.577	0.646	0.322	53.644
Johnston	0.365	0.444	0.243	76.508
Wylie	0.146	0.184	0.108	92.643
Killen	0.272	0.386	0.273	84.397
Richards	0.310	0.528	0.324	63.889
Gabriel	0.388	0.595	0.464	54.553
Tower	0.554	0.676	0.569	46.636
McKees Rocks	0.294	0.426	0.285	77.825
Dameron	0.549	0.558	0.266	75.000
Portman	0.269	0.281	0.066	87.379
Bonnie Brook	0.735	0.889	0.633	27.329

Table 44 (continued).

Assemblage	Genera J'	Resource J'	Habitat J'	Deer Acquisition
Carroll-Oregonia Rd.	0.636	0.666	0.410	59.701
Augusta	0.397	0.571	0.451	65.994
Slone	0.365	0.408	0.293	78.231
Fox Farm	0.442	0.654	0.438	59.378
Snag Creek	0.444	0.582	0.401	64.126
Riker	0.344	0.507	0.298	67.278
Mon City	0.433	0.549	0.356	58.722
Goolman	0.071	0.079	0.000	98.496
Buffalo	0.132	0.286	0.187	85.821

Table 45. Relative abundance of some faunal genera.

Assemblage	%Deer	%Elk	%Bear	%Turkey	%Opossum
Pyles	94.545	0.000	3.636	0.909	0.000
Leonard Haag (LW)	75.941	2.376	0.792	3.465	0.000
Hansen	88.889	3.704	0.000	0.000	0.000
Childers	93.913	0.373	0.414	1.366	0.000
Chesser	84.169	1.530	2.058	1.794	0.106
Peters Cave	48.387	0.000	0.000	3.226	1.613
White Rocks (LW)	92.022	0.557	0.000	1.237	0.000
Wise RS	43.629	0.000	0.000	4.247	0.000
Varner	58.207	12.090	0.782	5.055	0.000
Turpin (LW)	85.377	1.887	0.943	2.830	0.000
Raven Rocks	79.345	0.733	0.000	0.129	0.043
Barker's Bottom	76.545	3.273	6.545	9.636	1.091
White Rocks (LP)	88.324	0.538	0.269	2.221	0.135
Ryan	72.131	2.295	0.000	3.607	0.000
Muir	74.282	0.957	1.013	15.307	0.450
Thompson	79.027	1.033	1.398	7.964	0.912
Hobson	75.395	1.582	0.351	16.696	0.000
Gnagey	44.000	8.432	15.838	3.892	0.000
Mount Carbon	72.341	2.193	14.416	2.976	0.000
Turpin (LP)	78.451	0.673	1.010	5.051	1.010
Miller	84.461	0.501	0.501	9.023	0.000
Drew	61.958	0.762	0.059	20.047	0.000
Blain	65.944	2.382	0.738	14.718	0.452
Boyle	59.753	20.467	0.687	3.709	0.137
Philo II	81.425	0.485	0.036	8.938	0.000
Graham Village	85.732	9.848	0.379	2.399	0.000
Guilfoil	64.769	2.847	4.804	10.320	0.356
Henderson Rocks	82.051	0.142	0.142	10.185	0.000
Leonard Haag (LP)	84.459	1.351	0.000	4.730	1.351

Table 45 (continued).

Assemblage	%Deer	%Elk	%Bear	%Turkey	%Opossum
Duvall	53.947	0.000	3.947	0.000	2.632
Scarem	55.758	14.242	1.515	3.939	0.000
Johnston	79.091	3.636	1.169	4.156	0.000
Wylie	93.535	0.275	0.000	1.926	0.000
Killen	89.811	1.509	0.000	6.415	0.000
Richards	73.775	1.871	0.208	15.652	0.000
Gabriel	68.684	1.911	0.000	25.902	0.000
Tower	52.677	5.786	0.173	12.953	0.000
McKees Rocks	79.550	2.579	1.126	4.286	0.000
Dameron	73.333	0.000	0.000	0.000	0.000
Portman	87.379	1.942	0.000	0.000	0.000
Bonnie Brook	30.345	26.207	0.690	11.034	0.000
Carroll-Oregonia Rd.	60.606	3.030	3.030	1.515	0.000
Augusta	75.578	0.330	1.320	14.521	0.000
Slone	77.181	0.671	7.606	2.416	0.447
Fox Farm	67.814	3.441	2.886	14.206	0.000
Snag Creek	70.098	1.471	0.980	9.314	0.490
Riker	75.180	4.100	0.997	12.244	0.000
Mon City	67.864	0.599	0.000	19.162	0.000
Goolman	98.496	0.000	0.000	0.000	0.000
Buffalo	90.305	0.043	0.668	5.287	0.181

Table 46. Data of the aquatic index (includes size class 5 taxa).

Assemblage	Σ Terrestrial	Σ Aquatic	Aquatic Index
Pyles	111	0	0.000
Leonard Haag (LW)	1037	141	0.120
Hansen	27	2	0.069
Childers	2557	59	0.023
Chesser	1892	28	0.015
Peters Cave	68	1	0.014
White Rocks (LW)	1967	19	0.010
Wise RS	318	17	0.051
Varner	2357	83	0.034
Turpin (LW)	312	85	0.214
Raven Rocks	2559	5	0.002
Barker's Bottom	559	13	0.023
White Rocks (LP)	3568	59	0.016
Ryan	373	11	0.029
Muir	2038	41	0.020
Gnagey	2486	1743	0.412

Table 46 (continued).

Assemblage	Σ Terrestrial	Σ Aquatic	Aquatic Index
Thompson	1749	134	0.071
Hobson	592	16	0.026
Mt. Carbon	10088	912	0.083
Turpin (LP)	221	33	0.130
Miller	927	12	0.013
Drew	2024	254	0.112
Blain	4812	832	0.147
Boyle	717	20	0.027
Philo II	6105	114	0.018
Graham Village	789	10	0.013
Guilfoil	615	8	0.013
Henderson Rocks	1648	59	0.035
Duvall	143	2	0.014
Scarem	514	29	0.053
Johnston	856	21	0.024
Leonard Haag (LP)	163	17	0.094
Wylie	739	15	0.020
Killen	331	5	0.015
Richards	3762	61	0.016
Tower	1269	13	0.010
McKees Rocks	2928	336	0.103
Gabriel	939	12	0.013
Dameron	49	2	0.039
Portman	231	12	0.049
Bonnie Brook	166	20	0.108
Carroll-Oregonia	66	5	0.070
Augusta	310	21	0.063
Slone	2225	11	0.005
Fox Farm	1069	35	0.032
Snag Creek	238	9	0.036
Riker	1796	90	0.048
Mon City	591	140	0.192
Goolman	267	0	0.000
Buffalo	60169	1448	0.024

Table 47. Data of the rabbit and squirrel indices for local sequences.

Assemblage	Σ Artiodactyl	Σ Rabbit	Rabbit Index	Σ Squirrel	Squirrel Index
Chartiers Creek:					
Drew	1070	9	0.992	85	0.926
Boyle	584	11	0.982	34	0.945
Wylie	682	3	0.996	18	0.974
McKees Rocks	2261	6	0.997	60	0.974
Portman	184	5	0.974	1	0.995
West Virginia:					
Childers	2277	6	0.997	33	0.986
Hobson	438	2	0.995	9	0.980
Miller	678	0	1.000	16	0.977
Buffalo	52921	39	0.999	515	0.990
Kentucky:					
Pyles	104	0	1.000	0	1.000
Hansen	25	0	1.000	0	1.000
Killen	242	0	1.000	0	1.000
Thompson	1317	1	0.999	99	0.930
Snag Creek	146	1	0.993	15	0.907
Augusta	230	3	0.987	13	0.947
Fox Farm	642	14	0.979	38	0.944

Table 48. Data of the raccoon and turkey indices for local sequences.

Assemblage	Σ Artiodactyl	Σ Raccoon	Raccoon Index	Σ Turkey	Turkey Index
Chartiers Creek:					
Drew	1070	12	0.989	33	0.970
Boyle	584	20	0.967	221	0.725
Wylie	682	4	0.994	14	0.980
McKees Rocks	2261	58	0.975	35	0.985
Portman	184	6	0.968	0	1.000
West Virginia:					
Childers	2277	25	0.989	15	0.993
Hobson	438	18	0.961	251	0.636
Miller	678	11	0.984	16	0.977
Buffalo	52921	432	0.992	3097	0.945

Table 48 (continued).

Assemblage	Σ Artiodactyl	Σ Raccoon	Raccoon Index	Σ Turkey	Turkey Index
Kentucky:					
Pyles	104	0	1.000	143	0.421
Hansen	25	0	1.000	11	0.694
Killen	242	0	1.000	2	0.992
Thompson	1317	30	0.978	58	0.958
Augusta	230	7	0.970	66	0.777
Fox Farm	642	26	0.961	53	0.924
Snag Creek	146	7	0.954	72	0.670

HUMAN SKELETAL DATA

Table 49. Stature estimates.

Assemblage	Females			Males			Source
	n	height (cm)	sd	n	height (cm)	sd	
Chilton	1	154.44		4	159.31	4.83	Funkhouser and Webb (1937)[1]
Proctor	1	163.10			--		Sciulli et al. (1993)
Continental Construction		--		1	172.00		Sciulli et al. (1988)
Childers		--		1	161.33		Powell and Shott (1990)[1]
Hobson		--		1	157.81		Murphy (1968)[1]
Saddle (ELP)	1	153.30		2	164.50	4.10	Sciulli and Church (1995)
Blain		--		3	167.99	1.92	Lovejoy and Heiple (1970)[1]
O. C. Voss		--		6	164.62	3.65	Futrell (1966)[1]
Pinnacle	1	155.90			--		Burkett (1977)[1]
McKees Rocks	1	143.04			--		Doyle and Faingnaert (1975)[1]
Saddle (MLP)	2	155.70	8.06	2	165.30	4.81	Sciulli and Church (1995)
Bunnell		--		2	152.73	0.11	Lallo (1979)[1]
Madisonville	19	151.93		29	163.36		Hooton and Willoughby (1920)[1]

[1] Estimates calculated from reported measurements using formulae of Sciulli et al (1990).

Table 50. Frequency of traumatic injury.

Assemblage	n	Traumatic Injury (%)
Chilton	30	6.67
Continental Construction	1	100.00
Gartner	42	2.40
Hobson	9	11.10
Oglesby-Harris	1	0.00
Saddle (ELP)	6	0.00
Mt. Carbon	21	4.80
Blain	7	42.86
O. C. Voss	7	0.00
Boyle	15	6.67
Anderson	93	6.00
Henderson Rocks	6	0.00
Johnston	17	0.00
Duvall	9	11.10
Richards	32	81.30
Feurt	403	0.50
McKees Rocks	8	12.50
Saddle (MLP)	7	14.30
Bunnel Kame	9	0.00
Dameron	1	0.00
Augusta	10	10.00
Fox Farm	233	1.70
Snag Creek	1	100.00
Man	26	7.40
Larkin	10	20.00
Hardin	335	1.00
Buffalo	562	2.30
Madisonville	544	6.90

SETTLEMENT DATA

Table 51. Site type, location, topographic situation and defensive class. Missing data are indicated by --.

Locale	Site Type[1]	Location[2]	Situation[3]	Defense[4]
Pyles	NS	MV	UP	PSD
Leonard Haag	NS	MV	BB	UN
Hansen	NS	MV	BB	PND
Childers	NS	MV	BB	PSD
Waterplant	NS	MV	UP	PSD
Zencor	NS	MV	UP	PSD
Varner	NS	UV	UP	PD
W. S. Cole	NS	MV	UP	PSD
Turpin	NS	MV	BB	UN
Montague	NS	UV	BB	PD
46OH13	NS	UV	UP	PSD
Mount Carbon	NS	MV	NB	PD
Barker's Bottom	NS	MV	BB	UN
Baum	NS	MV	BB	UN
Enos Holmes	NS	MV	BB	UN
Ryan	NS	UV	UP	PD
Cramer	NS	MV	BB	UN
Muir	NS	MV	UP	PND
Gartner	NS	MV	BB	UN
Gnagey	NS	UV	BB	PD
Hobson	NS	MV	BB	UN
Thompson	NS	MV	BB	UN
Roseberry Farm	NS	MV	BB	PND
Saddle	NS	MV	UP	PSD
Guard	NS	MV	BB	UN
Hughes Farm	NS	UV	UP	PSD
Middle Site Island	NS	UV	BB	UN
Miller	NS	MV	BB	PND
Cleek-McCabe	NS	MV	BB	UN
Drew	NS	UV	NB	PSD
Blain	NS	MV	BB	UN
Boyle	NS	UV	UP	PSD
O.C. Voss	NS	MV	BB	UN
Graham Village	NS	MV	BB	UN
Horseshoe Johnson	NS	MV	BB	PND
Philo II	NS	MV	BB	PND
Anderson	NS	MV	BB	UN
Godwin-Portman	NS	UV	BB	PD
Guilfoil	NS	UV	UP	PSD

Table 51 (continued).

Locale	Site Type	Location	Situation	Defense
Henderson Rocks	NS	UV	UP	PSD
State Line	NS	MV	BB	PSD
Britt	NS	UV	NB	PND
Duvall	NS	UV	UP	PSD
Johnston	NS	UV	BB	PD
Scarem	NS	UV	NB	UN
Wylie	NS	UV	UP	PD
Incinerator	NS	MV	BB	PD
Killen	NS	MV	BB	UN
Madisonville	NS	MV	UP	PSD
Sand Ridge	NS	MV	UP	PSD
Campbell Farm	NS	MV	UP	PD
Howard Baum	NS	MV	BB	UN
Richards	NS	MV	BB	PND
Feurt	NS	MV	BB	UN
Baldwin	NS	MV	NB	UN
Francis	NS	UV	UP	PSD
Fuller's Hill	NS	UV	UP	PSD
Gabriel	NS	MV	BB	UN
Bunola	NS	UV	BB	PND
Kelso	NS	UV	UP	PSD
McJunkin	NS	UV	UP	PD
McKees Rocks	NS	UV	BB	PD
Tower	NS	UV	UP	PSD
Schomaker	NS	MV	BB	UN
Bonnie Brook	NS	UV	BB	PD
Buckner	NS	MV	NB	UN
Portman	NS	UV	BB	PD
Capitol View	NS	MV	--	--
Campbell Island	NS	MV	BB	UN
Augusta	NS	MV	BB	UN
Slone	NS	MV	NB	PD
Fox Farm	NS	MV	UP	PSD
Shippenport	NS	UV	BB	UN
Snag Creek	NS	MV	BB	UN
Riker	NS	MV	BB	PD
Mon City	NS	UV	NB	PND
Man	NS	MV	NB	PD
Larkin	NS	MV	BB	UN
Laughlin	NS	MV	BB	UN
Finley	NS	UV	UP	PSD
Household	NS	UV	UP	PD
Buffalo	NS	MV	BB	PD

Table 51 (continued).

Locale	Site Type	Location	Situation	Defense
DeVary	NS	MV	NB	UN
Hardin	NS	MV	BB	PSD
Hartley	NS	UV	UP	PSD
Sony	NS	UV	UP	PD
Rochester	NS	UV	BB	UN
46OH1	NS	UV	NB	UN
46BR2	NS	UV	--	--
Ashmore Farm	NS	UV	UP	PSD
Rinehart	NS	MV	--	--
Woods	DS	MV	BB	PND
Chesser Cave	SL	MV	RS	NR
Haystack Rockshelters	SL	MV	RS	NR
Peters Cave	SL	MV	RS	NR
Rogers Rockshelter	SL	MV	RS	NR
White Rocks	SL	UV	RS	NR
Wise Rockshelter	SL	MV	RS	NR
Raven Rocks	SL	MV	RS	NR
Wood-73	SL	MV	NB	NR
Carroll-Oregonia Road	SL	MV	NB	NR
Oglesby-Harris	SL	MV	BB	NR
Pinnacle	SL	UV	RS	NR
Proctor Rockshelter	SL	UV	RS	NR
Dameron	SL	MV	RS	NR
Goolman	SL	MV	NB	NR
Bunnell Kame	MF	MV	NR	NR
Chilton	MF	MV	NR	NR
Hawkins Ridge	MF	MV	NR	NR
Henderson Mound #2	MF	MV	NR	NR
Foster	MF	MV	NR	NR
C. L. Lewis	MF	MV	NR	NR
Newtown	MF?	MV	NR	NR
Continental Construction	MF?	MV	NR	NR
Watson	MF?	MV	NR	NR
Ufferman	MF?	MV	UP	UN
Ohioview	NS?	UV	BB	UN
A.M. Byers	--	UV	--	--
36AR?	--	UV	--	--
Barn	--	UV	--	--
Elliot	--	UV	--	--
Felix	--	UV	--	--
Globe Hill	--	UV	--	--
King	--	UV	--	--
Reservoir	--	UV	--	--

[1] NS, nucleated sedentary; DS, dispersed sedentary; SL, seasonal logistic; MF mortuary facility
[2] MV, Middle Valley; UV, Upper Valley
[3] UP, upland; BB, broad bottom; NB, narrow bottom; RS, rockshelter; NR, not relevant
[4] PND, probably not defensive; PSD, possibly defensive; PD, probably defensive; UN, unknown/insufficient information; NR, not relevant

Table 52. Settlement area and estimated roofed area for sedentary settlements. Missing data indicated by --.

Locale	Settlement Area (ha)	Estimated Roofed Area (m^2)
Pyles	1.47	--
Leonard Haag (LW)	2.43	--
Hansen	6.00	5234.25
Childers	0.90	1374.47
Water Plant	3.15	19900.00
Zencor	2.96	--
Woods	1.10	--
Varner	1.62	--
Montague	0.61	211.00
Baum	4.05	18844.64
Ryan	0.26	1960.00
Muir	3.80	2789.62
Cramer	1.40	--
Gnagey (Village #1)	0.11	281.00
Gnagey (Village #2)	0.20	154.00
Hobson	0.81	--
Thompson	2.00	--
Gartner	1.40	--
Watson	0.33	--
Roseberry	0.69	2703.36
Saddle (ELP)	0.35	--
Hughes Farm	1.62	--
Guard	2.37	--
Miller	0.29	--
Turpin	2.02	--
Drew	0.81	--
Cleek-McCabe	2.02	--
Blain	3.20	3472.20
Boyle	0.81	--
O. C. Voss	0.20	8355.82

Table 52 (continued).

Locale	Settlement Area (ha)	Estimated Roofed Area (m^2)
Philo II	1.40	14340.72
Graham	0.29	--
Godwin-Portman	0.35	--
Henderson Rocks	0.29	--
Anderson	0.50	--
Guilfoil	1.20	--
State Line	5.00	--
Johnston	1.90	8744.67
Scarem	0.49	--
Wylie	0.24	--
Leonard Haag (LP)	1.42	--
Killen	1.30	260.00
Incinerator	1.29	13830.00
Sand Ridge	1.40	--
Campbell Farm	0.84	16718.61
Richards	0.54	1815.40
Feurt	2.00	--
McJunkin	0.72	5475.38
McKees Rocks	6.07	--
Tower	0.79	--
Saddle (MLP)	0.71	--
Schomaker	1.02	1830.40
Bonnie Brook (Village #1)	0.11	147.22
Portman	0.13	--
Buckner	0.95	--
Capitol View	1.04	--
Bonnie Brook (Village #2)	0.15	200.12
Campbell Island	0.75	--
Slone	0.40	7660.00
Augusta	24.00	--
Fox Farm	16.00	--
Snag Creek	7.00	--
Larkin	7.70	--
Laughlin	5.00	--
Household	0.65	10043.33
Sony	8.90	--
Hartley	1.60	--
Hardin	4.60	71743.50
Buffalo #1 (upstream)	1.70	--
Buffalo #2 (downstream)	2.71	81763.20

Table 52 (continued).

Locale	Settlement Area (ha)	Estimated Roofed Area (m^2)
Madisonville	2.00	--
Rochester	1.01	--
Ashmore Farm	1.00	--

Table 53. Calculated subterranean pit volumes and semisubterranean pit areas.

Locale	n	Mean Pit Volume (m^3)	SD	Locale	n	Mean Pit Area (m^2)	SD
Hansen	8	0.0004	0.0003	Montague	1	1.4593	
Childers	51	0.2150	0.4449	Ryan	1	2.9828	
Woods	18	0.4976	0.5606	Gnagey	1	3.2657	
Blain	4	1.1984	0.4486	Johnston	1	3.2835	
Graham	8	1.5295	0.6334	Wylie	2	2.5800	0.3499
Howard Baum	4	1.1063	0.6265	Portman	3	2.3981	0.8194
Schomaker	7	0.8159	0.5050	Mon City	1	3.6285	
Campbell Island	2	0.8801	0.8033	Household	5	3.8446	0.4756
Man	6	0.1966	0.2273	Ashmore	1	2.8274	
Tower	3	0.6227	0.0385				
McKees Rocks	4	1.0884	0.3163				

APPENDIX C: CONTROLLED FEEDING STUDY

This project was undertaken to gain a better understanding of diet-tissue relationships in an animal model known to be an excellent nutritional surrogate for humans, the domestic pig. Four experimental diets that differ in their stable carbon isotope and trace element compositions were each fed to five pigs from shortly after weaning until they reached reproductive maturity. Skeletal samples were obtained from each of the pigs for direct comparison with the experimental diets. Although the analyses are not yet complete, data relevant to the discussion of the isotopic relationship of collagen to diet are presented here.

EXPERIMENTAL STRUCTURE

Piglets were entered into the study when they reached eight weeks (56.95 ± 1.889 days) of age and weighed about 18 kg. By that time, the animals had been weaned for nearly 5 weeks and no longer required milk products. Thus, throughout the duration of the study, no major changes occurred in the physiological function of the digestive tract, nor were dietary changes necessary to meet the nutritional requirements of the animals. The study concluded approximately seven months later, when the pigs were nine months (278.45 ± 3.35 days) of age (approximately 158 kg). Reproductive maturity, usually attained by 6 - 7 months of age (Mount and Ingram 1971; Pond and Houpt 1978; Stabenfeldt and Edqvist 1984), was confirmed by observing at least one estrous cycle for each animal.

Although it might be useful to compare isotopic fractionation between the different sex classes, only gilts (nulliparous female pigs) were used in this study. There are metabolic differences between females and males that could potentially influence the isotopic composition of their tissues, but no controlled studies (e.g., DeNiro and Schoeninger 1983) have yet produced evidence of differences in isotopic

discrimination between the sexes. Accordingly, whenever sexual differences in isotope ratios have been documented, they have been attributed to behavioral, not physiological, variation. In this case, the additional difficulties and expense (isolation in individual pens, greater pen area for small groups, lower market value) involved in maintaining intact males once they have reached puberty, the altered metabolism of castrated males, and the greater sample numbers that would be required for the addition of males to the study dictated that the experimental animals be restricted to only females.

The pigs used were from seven litter outcome groups (Table 54) that were delivered over a range of three days. Litters 77, 79, 80, and 81 had at least four pigs, so each diet received one pig from those litters. The litter outcome group of the fifth pig in each diet group varied; litter 84 was the source of the fifth pig of Diets 1 and 4, litter 83 for the fifth pig of Diet 2, and litter 78 for the fifth pig of Diet 3. Pigs from the litter-outcome groups were randomly assigned to the diets. The pigs spent 221.5 ± 7.18 days (just over 79% of their lifetimes) on the experimental rations (Figure 169). During that time, the pigs were normal, healthy subjects, free from infectious diseases or deformities that might affect their ability to eat or metabolize food.

Table 54. Pig-diet assignments.

Outcome Group	Diet 1	Diet 2	Diet 3	Diet 4
Litter 77	77-9	77-10	77-8	77-7
Litter 79	79-11	79-9	79-8	79-14
Litter 80	80-5	80-7	80-6	80-8
Litter 81	81-6	81-7	81-10	81-9
Mixed	84-7	83-11	78-15	84-8

DIETARY INTAKE

When the four groups of pigs were entered into the study, they had already consumed varying amounts of other diets beyond the maternal diet (Figure 168). These diets and the schedule with which they are administered are part of the established protocol at the Facility, and they are designed to meet the specific nutritional needs of young, growing piglets. Table 55 summarizes the ingredients for each of these diets, as well as the lactating sow diet eaten by the piglets' mothers. The diets, which all contain both C_3 and C_4 sources, are clearly mixed isotopically.

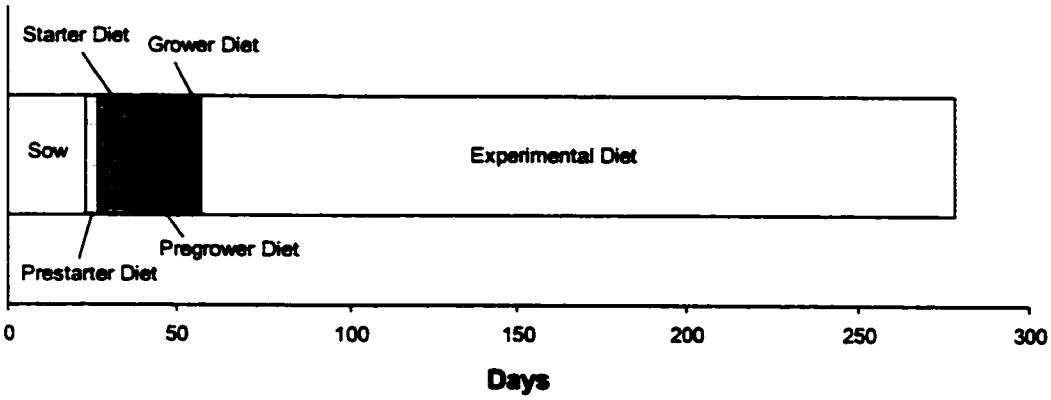


Figure 169. **Number of days on each diet during the lifespan of the pigs used in the controlled feeding experiment.**

Even after seven months on the experimental feeds, it is possible that the pig bones may retain a chemical signature reflecting the isotopic composition of the pre-experimental diets, i.e., there may be an isotopic memory. However, given the rate of growth these pigs experienced during the study, any such contribution is likely to be quite small. Indeed, Schroeder and Ben-Ghedalia (1986) suggest that, in growing animals, a weight gain of roughly ten times translates to more than 90% of the carbon in body tissues coming from the current feed. The weight gain experienced by these pigs was nearly a nine-fold gain, nearly twice that of Hare

Table 55. Composition (weight %) of Lactating Sow Diet (Formula 1008), Pre-Starter Diet (Formula 1000), Starter Diet (Formula 1001), Pre-Grower Diet (Formula 1042) and Grower Diet (Formula 1003).

Ingredient	Lactating Sow	Pre-Starter	Starter	Pre-Grower	Grower
Barley	40.20	27.90	--	--	47.55
Corn	30.00	29.00	15.00	34.325	20.00
Peas	11.00	--	--	--	20.00
Wheat	--	--	40.30	30.00	--
Soybean Meal	11.00	7.00	6.00	23.00	8.00
Animal Fat	4.00	4.00	3.00	3.00	1.00
Dried Whey	--	15.00	15.00	5.00	--
Dried Skim Milk	--	--	12.00	--	--
Banminth	--	--	--	1.00	--
Plasma Protein	--	8.00	--	--	--
Fishmeal	--	4.00	5.00	--	--
Dicalcium Phosphate	1.40	2.40	0.80	1.40	1.40
Ground Limestone	1.00	0.60	0.60	0.90	0.90
Sodium Chloride	0.45	--	0.30	0.30	0.30
Sow Vitamin	0.50	--	--	--	--
Vitamin Premix	--	0.60	0.65	0.50	0.50
Magnesium Sulfate	0.15	--	--	--	--
Copper Sulfate	--	0.10	--	0.05	0.05
Selenium Premix	0.15	--	--	0.05	0.10
Trace Mineral Premix	0.10	0.10	0.15	0.20	0.10
Trace Mineral 50	0.05	--	--	--	--
Lysine	--	0.20	0.20	0.15	--
Methionine	--	0.10	--	--	0.10
Apralan 7.15	--	1.00	1.00	--	--
Tylan-40	--	--	--	0.125	--
Total	100.00	100.00	100.00	100.00	100.00

et al.'s (1991) experiment in which the isotopic memory was judged to be slight, if at all.

Since the goal of this study is to examine variation in isotopic fractionation under simple controlled conditions, the four experimental diets consumed by the pigs were balanced nutritionally. The nutrient compositions of these four diets (Table 56) were calculated to meet the nutritional requirements for 20 – 50 kg swine as recommended by the Subcommittee on Swine Nutrition of the National Research Council (National Research Council 1988). The nutrient requirements of 20 – 50 kg swine equal or exceed (but not dangerously so) those of more mature animals, thus diets designed for the former will be adequate for the latter. In addition to protein and energy sources chosen for their isotopic composition, each ground feed contains animal fat (to decrease dust), mineral supplements and in some cases, a supplement of the essential amino acid lysine.

Table 56. Nutrient composition of the four experimental diets compared to NRC requirements. The nutrient calculations are based on published compositions found in National Research Council (1988) and Froseth and Miller (1992).

Nutrient	Requirements	Diet 1	Diet 2	Diet 3	Diet 4
Energy Concentration (kcal DE/kg diet)	3396.00	3480.28	3425.11	3634.58	3571.78
Protein (%)	15.00	16.75	15.25	32.21	29.00
Essential Amino Acids (%):					
Arginine	0.25	0.98	0.99	1.19	1.06
Histidine	0.22	0.40	0.42	0.74	0.71
Isoleucine	0.46	0.64	0.65	1.29	1.20
Leucine	0.60	1.16	1.58	4.79	4.80
Lysine	0.75	0.75	0.75	0.75	0.75
Methionine & Cystine	0.41	0.58	0.56	1.42	1.33
Phenylalanine & Tyrosine	0.66	1.31	1.38	3.56	3.38
Threonine	0.48	0.56	0.62	1.14	1.09
Tryptophan	0.12	0.18	0.19	0.18	0.17
Valine	0.48	0.81	0.81	1.61	1.50
Linoleic Acid (%)	0.10	0.76	1.80	0.46	1.22

Table 56 (continued).

Nutrient	Requirements	Diet 1	Diet 2	Diet 3	Diet 4
Mineral Elements:					
Calcium (%)	0.60	0.71	0.70	0.71	0.71
Phosphorus, Total (%)	0.50	0.60	0.60	0.60	0.60
Sodium (%)	0.10	0.14	0.13	0.15	0.14
Chlorine (%)	0.08	0.28	0.23	0.60	0.62
Magnesium (%)	0.04	0.16	0.14	0.11	0.09
Potassium (%)	0.23	0.64	0.64	0.68	0.68
Copper (mg/kg)	4.00	235.98	218.49	228.24	237.55
Iodine (mg/kg)	0.14	0.38	0.19	0.19	0.38
Iron (mg/kg)	60.00	359.66	194.50	274.19	400.04
Manganese (mg/kg)	2.00	120.21	61.06	62.59	105.64
Selenium (mg/kg)	0.15	0.35	0.37	0.37	0.37
Zinc (mg/kg)	60.00	136.85	76.45	81.53	125.71
Vitamins:					
Vitamin A (mg/kg)	0.39	2.10	1.75	1.75	2.10
Vitamin D (mg/kg)	0.004	0.39	0.33	0.33	0.39
Vitamin E (mg/kg)	11.00	22.81	28.01	26.68	34.07
Vitamin K (mg/kg)	0.50	1.86	1.55	1.55	1.86
Biotin (mg/kg)	0.05	0.18	0.11	0.17	0.11
Choline (g/kg)	0.30	0.77	0.98	0.44	0.54
Folacin (mg/kg)	0.30	22.50	0.36	14.63	0.29
Niacin, Available (mg/kg)	10.00	31.73	28.67	45.15	44.60
Pantothenic Acid (mg/kg)	8.00	28.71	11.63	19.91	10.23
Riboflavin (mg/kg)	2.50	3.48	3.13	3.23	3.51
Thiamin (mg/kg)	1.00	2.24	3.46	1.32	2.18
Vitamin B6 (mg/kg)	1.00	21.39	5.72	16.18	6.05
Vitamin B12 (mg/kg)	10.00	70.50	58.75	58.75	70.50

Table 57 lists the ingredients combined to form each of the experimental diets. Experimental Diet #1 has both C_3 protein and energy sources; Experimental Diet #2 has C_3 protein and C_4 energy sources; Experimental Diet #3 has C_4 protein and C_3 energy sources; and finally, Experimental Diet #4 has both C_4 protein and energy sources.

Table 57. Composition (weight %) of Diet 1 (Formula 1203), Diet 2 (Formula 1204), Diet 3 (Formula 1205) and Diet 4 (Formula 1206).

Ingredient	Diet 1	Diet 2	Diet 3	Diet 4
Barley	83.088	--	53.70	--
Corn	--	78.463	--	55.263
Soybean Meal	13.00	17.60	--	--
Corn Gluten Meal	--	--	41.65	39.65
Animal Fat	1.00	1.00	1.00	1.00
Dicalcium Phosphate	1.125	1.45	1.175	1.462
Ground Limestone	0.937	0.737	1.025	0.875
Sodium Chloride	0.30	0.30	0.30	0.30
Vitamin Premix	0.30	0.25	0.25	0.30
Trace Mineral Premix	0.10	0.05	0.05	0.10
Selenium Premix	0.10	0.10	--	--
Copper Sulfate	0.05	0.05	0.05	0.05
Lysine	--	--	0.10	0.20
Potassium Chloride	--	--	0.70	0.80
Total	100.00	100.00	100.00	100.00

To prevent obesity, the pigs were fed in amounts scaled to their body size. When first enrolled at about 18 kg, feed was available *ad libitum* and the young pigs consumed 5 – 7% of their body weight, or approximately 0.9 – 1.3 kg/day. Food availability was limited when the pigs reached 6.4 months of age (approximately 104 kg); at that point, they consumed 3 – 3.5% of their body weight,

or approximately 3.1 – 3.7 kg/day. Water was available *ad libitum*. One 200 – 300 g sample of each of the pre-experimental diets was collected as the animals consumed those diets prior to the beginning of the experiment; over the duration of the study, six samples of similar size were collected from each of the experimental diets.

FEED SAMPLE ANALYSIS

To assess how well the protein composition and content of the diets met the National Research Council requirements and the experimental design, samples from each of the feeds were analyzed for their amino acid compositions.[78] In Figure 170, I compare the amino acid profiles of the experimental and pre-experimental feeds. The amino acid compositions of the experimental diets are more variable than the pre-experimental ones, but they generally show a similar overall pattern; there are no severe deficiencies or toxicities apparent.

As Figure 171a shows, the relative concentrations of amino acids in the experimental diets compare favorably with the calculated values in Table 56. The individual symbols for each diet represent different amino acids. The measured amino acid concentrations in all four diets are significantly correlated with the estimated concentrations, although, as the slope of the linear regression lines indicate, they are in consistently lower concentrations than designed (Table 58).

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[78] For each sample, 2 – 4 g of feed (ground in an electric coffee grinder to pass through a 0.0 Φ sieve) were weighed into a clean testtube with 6.0 M HCl, phenol, mercaptoethanol and norleucine standard, and sealed under vacuum after repeated argon flushes. After hydrolyzing for 20 hours at 115°C, the samples were evaporated and solubilized in lithium buffer. The samples were analyzed on a model 7300 Beckman Amino Acid Analyzer at AAA Laboratory, Mercer Island, WA. Serine and threonine values were increased by 10% and 5%, respectively, to compensate for losses during hydrolysis.

Likewise, the proportion of protein (by weight) in each of the diets is quite close to the estimated values, but generally a little lower than expected (Figure 171b).

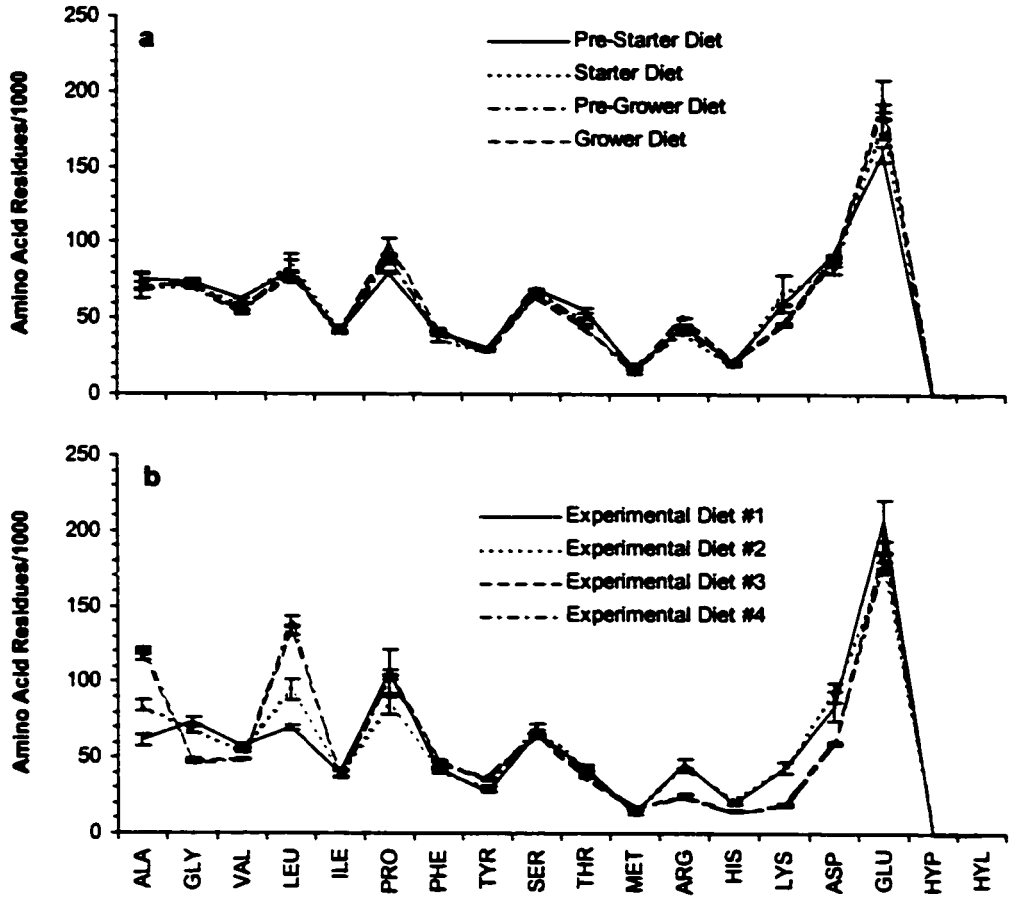


Figure 170. **Mean (± 1 sd) amino acid composition of diets.** (a) pre-experimental (n = 2 duplicates/diet) and (b) experimental (n = 6 duplicates/diet, except Diet #1 where n = 5 duplicates) diets. ALA, alanine; GLY, glycine; VAL, valine; LEU, leucine; ILE, isoleucine; PRO, proline; PHE, phenylalanine; TYR, tyrosine; SER, serine; THR, threonine; MET, methionine; ARG, arginine; HIS, histidine; LYS, lysine; ASP, aspartic acid; GLU, glutamic acid; HYP, hydroxyproline; HYL, hydroxylysine.

Because there are some amino acids present in the feeds that were not included in my analysis (e.g., tryptophan and cystine), the actual protein content is slightly higher than the measured content that is plotted. From this, I

conclude that the experimental diets correspond well with the dietary design, that they are not protein-deficient, and that there appear to be no deficiencies or toxicities that might affect digestion, absorption or tissue synthesis in an uncontrolled manner.

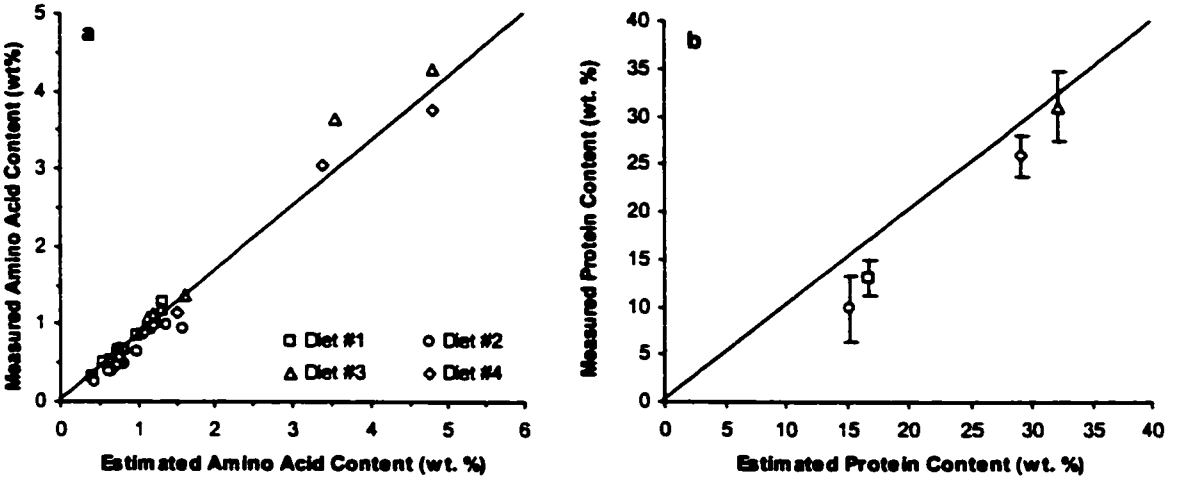


Figure 171. **Measured vs. estimated dietary compositions.** (a) Mean measured vs. estimated amino acid composition of the four experimental diets. (b) Mean measured (± 1 sd) vs. estimated protein content of the four experimental diets. The diagonal lines plot hypothetical 1:1 relationships between the measured and estimated values.

Table 58. Correlation, significance and slope of regression for comparisons of measured vs. estimated amino acid composition of experimental pig diets.

Experimental Diet	*r*	*p*	Slope
Diet #1	.980	<.001	1.016
Diet #2	.980	<.001	1.466
Diet #3	.994	<.001	1.042
Diet #4	.994	<.001	1.201

Bulk samples of the feeds (ground to pass a 0.0 Φ sieve) were also analyzed to determine the isotopic composition of the whole diet. Each of the pre-

experimental diets was split and two replicate analyses of the diet were conducted; if they varied significantly, a third $\delta^{13}C$ determination was made. The results for the pre-experimental diets are listed in Table 59. As suspected from considering the ingredient lists of these diets, the pre-experimental diets are mixed isotopically. This helped to reduce the amount of time necessary for the animals to reach equilibration with the experimental diets.

Table 59. Stable carbon isotopic composition of the pre-experiment diets and the four experimental diets consumed by the pigs in the study. For each of the experimental diets, two or three replicates were analyzed for three samples, collected at different times during the study (A, early; G, midway; and K, late).

Diet		Replicate #1		Replicate #2		Replicate #3		Sample Average		Diet Average	
		$\delta^{13}C$	SE	$\delta^{13}C$	SE	$\delta^{13}C$	SE	Avg. $\delta^{13}C$	SE	Avg. $\delta^{13}C$	SE
Pre-experiment Diets:											
Pre-Starter		-20.59	0.01	-19.80	0.01	-20.21	0.01	-20.20	0.40		
Starter		-20.18	0.02	-21.11	0.03	-20.39	0.00	-20.56	0.49		
Pre-Grower		-19.60	0.01	-19.21	0.01			-19.41	0.28		
Grower		-20.58	0.01	-20.67	0.01			-20.63	0.06		
Experimental Diets:											
Diet	Sample										
#1	A	-24.70	0.01	-24.44	0.01	--	--	-24.57	0.18		
	G	-25.21	0.01	-24.63	0.01	--	--	-24.92	0.41		
	K	-24.63	0.03	-24.51	0.04	--	--	-24.57	0.09	-24.69	0.33
#2	A	-14.99	0.01	-13.95	0.02	-14.42	0.01	-14.45	0.52		
	G	-14.82	0.03	-14.48	0.01	--	--	-14.65	0.24		
	K	-16.39	0.00	-15.54	0.03	-15.70	0.01	-15.88	0.45	-14.99	0.88
#3	A	-17.75	0.01	-16.83	0.01	--	--	-17.29	0.65		
	G	-18.56	0.03	-17.38	0.01	--	--	-17.97	0.83		
	K	-19.34	0.01	-18.07	0.00	-20.08	0.01	-19.16	1.02	-18.14	1.27
#4	A	-12.26	0.05	-12.83	0.01	--	--	-12.55	0.40		
	G	-12.42	0.03	-12.10	0.01	--	--	-12.26	0.23		
	K	-12.46	0.02	-12.35	0.01	--	--	-12.41	0.08	-12.40	0.31

Three of the six large samples collected for each of the experimental diets have been analyzed isotopically. Each sample was split to provide replicate isotopic determinations for that sample. Again, if they varied significantly, a third

$\delta^{13}C$ determination was made. The results are presented in Table 59. The bulk isotopic compositions of these diets are distinctly different, with C_3 and C_4 endmembers and two isotopically-mixed diets represented.

Isotopic Composition of Dietary Protein, Estimated

To facilitate comparisons with the rodent data, the isotopic composition of the dietary protein in the four experimental diets was estimated. First, the relative percentage of protein contributed to each diet by the different C_3 and C_4 plant sources (National Research Council 1988; Froseth and Miller 1992) was calculated. Then, using published $\delta^{13}C$ ratios for the protein components of those ingredients, the isotopic contribution to the diet made by each protein source was determined and summed. The values assumed and corresponding estimates of the isotopic composition of dietary protein in the four experimental diets are presented in Table 60. Although rather crude, these estimates will provide some sense of the impact of dietary protein on collagen $\delta^{13}C$ values in pigs; the precision of the estimates will improve as more isotopic analyses are completed.

Isotopic Analysis of Pig Collagen

At the end of the experiment, the pigs were euthanized using fixed bolt stunting at the Washington State University Meat Science Lab in two groups, one week apart. Both femora and accompanying patellae were removed from each animal, labeled and frozen. After thawing, adhering tissues were manually removed and the bones were dried in a low temperature oven. The dry bones were placed in a dermestid beetle colony for further cleaning. Four bone samples were removed from the midshaft of each left femur and cleaned in an ultrasonic bath.

The primary concern in isolating collagen from modern skeletal samples for isotopic analysis is eliminating potential contamination due to the inclusion of lipids in the extracted material. Lipids have been found to contribute

up to 3.5% to the weight of fresh demineralized pig bone (Liden et al. 1995). Because they tend to be depleted isotopically relative to other biochemicals (DeNiro and Epstein 1978; Liden et al. 1995), their inclusion in the collagen extract could make the collagen appear to be more negative than it truly is. It has been argued (see Appendix D) that soaking the bone in NaOH during the extraction process removes lipids.[79]

Table 60. Estimated isotopic composition of dietary protein in the experimental diets. Calculations include, for each protein source in each diet, the proportion of protein they contribute toward total protein in the diet and the $\delta^{13}C$ value of that protein.

Diet	Protein Source #1	%	Protein $\delta^{13}C$	Protein Source #2	%	Protein $\delta^{13}C$	$\delta^{13}C$ Total
1	barley[1]	62.06	-26.70	soybean meal[2]	37.94	-24.60	-25.90
2	soybean meal	56.20	-24.60	ground corn[3]	43.80	-12.50	-19.30
3	corn gluten meal	79.14	-12.50	barley	20.86	-26.70	-15.46
4	corn gluten meal	83.79	-12.50	ground corn	16.21	-12.50	-12.50

[1] Mitchell et al. (1993) report a $\delta^{13}C$ value of barley at -25.3 ‰; I assumed a grain/protein fractionation factor similar to other C_3 cereals (e.g., wheat) of -1.4 ‰ (Tieszen 1991).

[2] From Tieszen and Fagre (1993b); I note there is some discrepancy with Ambrose and Norr's determination at -25.3 ‰ (Ambrose and Norr 1993).

[3] From Tieszen and Fagre (1993a); the same estimate of corn protein was extended to all corn sources.

Of the four bone chunks removed from each pig femur, collagen was extracted from two using the standard HCl extraction technique and from two using the NaOH extraction technique (see Appendix D for detailed descriptions of these two extraction protocols), with one slight modification. As the bone chunks were demineralized, it was clear that some lipids (visible as a "greasy scum" in the weak

[79] Other approaches to minimizing contamination by lipids of modern collagen extracts include soaking the bone in organic solvents (e.g., EDTA [ethylenediaminetetraacetic acid], ether, chloroform, or methanol); since this step may add exogenous carbon to the product, I chose to avoid it in my extractions.

acid) were being liberated; thus, rather than retain all of the residue captured by the glass-fiber filter (which included this "scum") during acid changes, only the collagen pseudomorph was kept. By the time the samples had been filtered following gelatinization, there was no visible evidence of a greasy "scum" in the samples. Thus, both techniques removed at least some potential contaminants. Stable carbon isotope determinations were made as described in Appendix D and the results are presented in Table 61.

Table 61. Stable carbon isotopic composition of collagen from pigs raised on controlled diets. Two different techniques (standard HCl and NaOH soak) were used to isolate two replicates each of collagen from each animal.

		Replicate 1		Replicate 2		Pig Average	
Diet	Pig	$\delta^{13}C$	SE	$\delta^{13}C$	SE	mean $\delta^{13}C$	SE
HCl extraction:							
1	77-9	-21.13	0.01	-21.63	0.00	-21.38	0.35
1	79-11	-21.45	0.02	-21.35	0.05	-21.40	0.08
1	80-5	-21.54	0.01	-21.40	0.08	-21.47	0.11
1	81-6	-21.47	0.00	-21.49	0.01	-21.48	0.02
1	84-7	-21.40	0.03	-21.40	0.04	-21.40	0.04
2	77-10	-14.77	0.02	-14.78	0.00	-14.78	0.02
2	79-9	-15.13	0.01	-14.98	0.00	-15.06	0.11
2	80-7	-14.82	0.03	-14.35	0.02	-14.59	0.33
2	81-7	-15.16	0.07	-14.23	0.02	-14.70	0.66
2	83-11	-14.42	0.03	-15.01	0.01	-14.72	0.42
3	77-8	-12.78	0.01	-13.95	0.04	-13.37	0.83
3	78-15	-13.79	0.02	-13.31	0.13	-13.55	0.35
3	79-8	-12.94	0.00	-12.55	0.03	-12.75	0.28
3	80-6	-14.25	0.02	-13.73	0.07	-13.99	0.37
3	81-10	-13.55	0.01	-13.18	0.01	-13.37	0.26
4	77-7	-10.00	0.00	-8.97	0.00	-9.49	0.73
4	79-14	-8.97	0.07	-10.00	0.01	-9.49	0.73
4	80-8	-9.41	0.02	-10.10	0.06	-9.76	0.49
4	81-9	-9.74	0.02	-10.75	0.02	-10.25	0.71
4	84-8	-9.88	0.04	-10.58	0.04	-10.23	0.50

Table 61 (continued).

Diet	Pig	Replicate 1 $\delta^{13}C$	SE	Replicate 2 $\delta^{13}C$	SE	Pig Average mean $\delta^{13}C$	SE
NaOH extraction:							
1	77-9	-21.46	0.02	-21.46	0.02	-21.46	0.02
1	79-11	-21.66	0.03	-20.95	0.04	-21.31	0.50
1	80-5	-21.55	0.01	-21.70	0.02	-21.63	0.11
1	81-6	-21.53	0.02	-21.57	0.03	-21.55	0.04
1	84-7	-21.51	0.01	-21.64	0.05	-21.58	0.10
2	77-10	-14.25	0.03	-14.47	0.03	-14.36	0.16
2	79-9	-14.21	0.03	-14.45	0.09	-14.33	0.18
2	80-7	-14.35	0.01	-15.14	0.07	-14.75	0.56
2	81-7	-14.66	0.03	-14.98	0.03	-14.82	0.23
2	83-11	-14.61	0.00	-14.58	0.02	-14.60	0.03
3	77-8	-13.19	0.01	-13.28	0.06	-13.24	0.08
3	78-15	-14.08	0.02	-13.51	0.07	-13.80	0.41
3	79-8	-13.83	0.02	-13.02	0.00	-13.43	0.57
3	80-6	-14.16	0.01	-13.98	0.01	-14.07	0.13
3	81-10	-13.17	0.06	-13.06	0.09	-13.12	0.11
4	77-7	-9.71	0.04	-9.47	0.04	-9.59	0.17
4	79-14	-8.95	0.03	-9.44	0.01	-9.20	0.35
4	80-8	-9.13	0.01	-9.67	0.02	-9.40	0.38
4	81-9	-9.33	0.01	-10.00	0.11	-9.67	0.48
4	84-8	-9.35	0.00	-9.92	0.02	-9.64	0.40

If the NaOH soak successfully removed lipids that the standard treatment did not, then there should be predictable differences in the isotope ratios of the resulting collagen. The NaOH-treated samples should be more positive than the standard samples. A paired-sample t-test failed to reject the null hypothesis that $\delta^{13}C$ values of the NaOH-treated samples were $\leq$ the standard HCl-treated samples ($t = -1.102$; $p = .142$). Thus, there is apparently no statistically significant difference in the isotopic composition of collagen extracted following the two protocols.

There is, however, reason to prefer the NaOH-soaked samples over those lacking that treatment. First, consider the difference between the two replicates of each pig sample. Overall, the standard errors (SEs) for the individual averages are quite large (mean ± 1 SE = 0.310 ± 0.053), indicating a *significant* amount of variation between replicates. (For comparison, the mean [± 1 SE] difference in $\delta^{13}C$ values between replicates of archaeological samples analyzed in this study is 0.015 ± 0.015 ‰.) This extreme variation in the modern materials may well be due to the variable input of lipids to the isotopic composition of the extracted collagen. The NaOH samples tend to show much less variation (Figure 172). Although not statistically significant at $\alpha = .05$ ($t = 1.638$; $p = .111$), the greater precision offered by the NaOH-treated samples is preferred here.

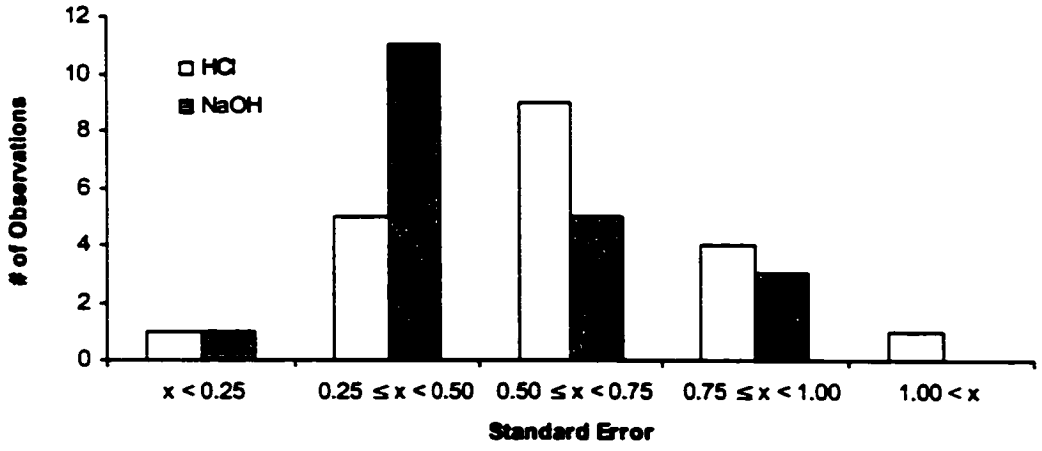


Figure 172. **Standard errors of $\delta^{13}C$ values determined for replicate samples of pig collagen using two extraction techniques.**

The relatively low precision of the replicate extractions does not translate into great variation among pigs in each diet. The average isotopic composition for each diet group is shown in Table 62. The SEs, as calculated for this table, do not compound the errors associated with the replicate analyses. This is to allow comparisons with the SEs as calculated by other controlled-feeding studies that consider the amount of variation within groups eating specific diets. For Tieszen and Fagre (1993b), SEs (n = 4) associated with the isotopic composition

of collagen from mice raised on different diets range from 0.09 to 0.48 ‰. From Deniro and Schoeninger's (1983) report on variation in the isotopic composition of bone collagen from mink and rabbits raised on controlled diets, I calculate that their SEs were 0.05 (n = 15) and 0.02 ‰ (n = 21), respectively; note, however, that the latter estimate is likely artificially low due to multiple determinations from different bones of the same individual, as only three rabbits were enrolled in the study.

Table 62. Average isotopic composition of collagen from pigs raised on different diets. The results from both extraction techniques are shown.

	HCl-treated bones		NaOH-treated bones	
Diet	mean $\delta^{13}C$	SE	mean $\delta^{13}C$	SE
1	-21.43	0.02	-21.50	0.06
2	-14.77	0.09	-14.57	0.11
3	-13.40	0.22	-13.53	0.20
4	-9.84	0.19	-9.50	0.10

If lipids pose a severe problem in these samples, the $\delta^{13}C$ values of collagen from pigs raised on Diets 1 and 4 should be significantly more negative than the lipid-free collagen of the pigs raised on similar diets by Hare et al. (1991). Diet #1 here is isotopically similar to their C_3 diet, whereas Diet #4 is isotopically the same as their C_4 diet (Table 63). As the table shows, for the C_3 based diet, my pigs are more enriched than Hare et al.'s pigs relative to the isotopic composition of their diets. For the C_4-based diet, my pigs are slightly more depleted than theirs; since they do not report how much variation underlies their samples, it is not clear whether this 0.30 ‰ difference can be considered a significant departure that might be due to the inclusion of lipids in my collagen samples. Since there are no consistent differences, I conclude that lipids may pose a slight problem to be resolved in the future with lipid-free extractions. For the purposes of the discussion on controlled-feeding studies and their implications for isotopic analysis of bone

collagen from archaeological human bones, I use the isotopic compositions of the NaOH-extracted collagen.

Table 63. Comparison of isotopic composition of collagen from pigs raised on controlled diets between this study and that of Hare et al. (1991).

This Study			Hare et al. (1991)		
Diet $\delta^{13}C$	Pigs $\delta^{13}C$	Difference	Diet $\delta^{13}C$	Pigs $\delta^{13}C$	Difference
-24.69	-21.50	+ 3.19	-25.3	-23.9	+ 1.4
-12.40	-9.50	+ 2.90	-12.4	-9.2	+ 3.2

APPENDIX D: "COLLAGEN" EXTRACTION AND EVALUATION

I conducted a limited number of tests in an effort to establish quickly the effect different extraction protocols might have on the archaeological bone samples available for this research. Specifically, I compared the extracts from three different protocols (Figure 173), here labeled the standard, NaOH, and ultrafiltration protocols, in terms of both sample quality and resulting isotope ratios. The first two techniques are used frequently in paleodietary studies and the last has only been applied to sample preparation for ^{14}C dating. Other protocols in use (e.g., using collagenase, EDTA, chromatography) are more expensive and/or require greater expertise.

The first step involved the mechanical separation of 2 – 3 gm of bone from sediments, rootlets, and other materials. Isolated occurrences of substances such as ink, glue, or fingernail polish were physically removed by excising the adjacent bone with a razor blade; sawcuts were cleaned with sandpaper. The bone was cleaned manually of particulate contaminants with brushes, followed by placement in an ultrasonic cleaner with repeated changes of deionized water until the water remained clear. This processing did not remove all particulate matter, of course, but it was effective in removing the big chunks. The samples were then dried at a low temperature ($\approx 50°C$), cooled and weighed.

The second step involved dissolution of the mineral phase and removal of other acid-soluble materials (e.g., fulvic acids). Although some extraction protocols call for powdering the bone prior to demineralization, Schoeninger et al. (1989) demonstrated that bone left as chunks gives better results (higher yields, more collagen-like amino acid compositions) than powdered bone. Additionally, some protocols (e.g., Ambrose 1990; Longin 1971) call for the use of strong acids and/or heat to speed up the demineralization process, but longer times with more dilute acids at room temperature give better results (higher yields, lower salt

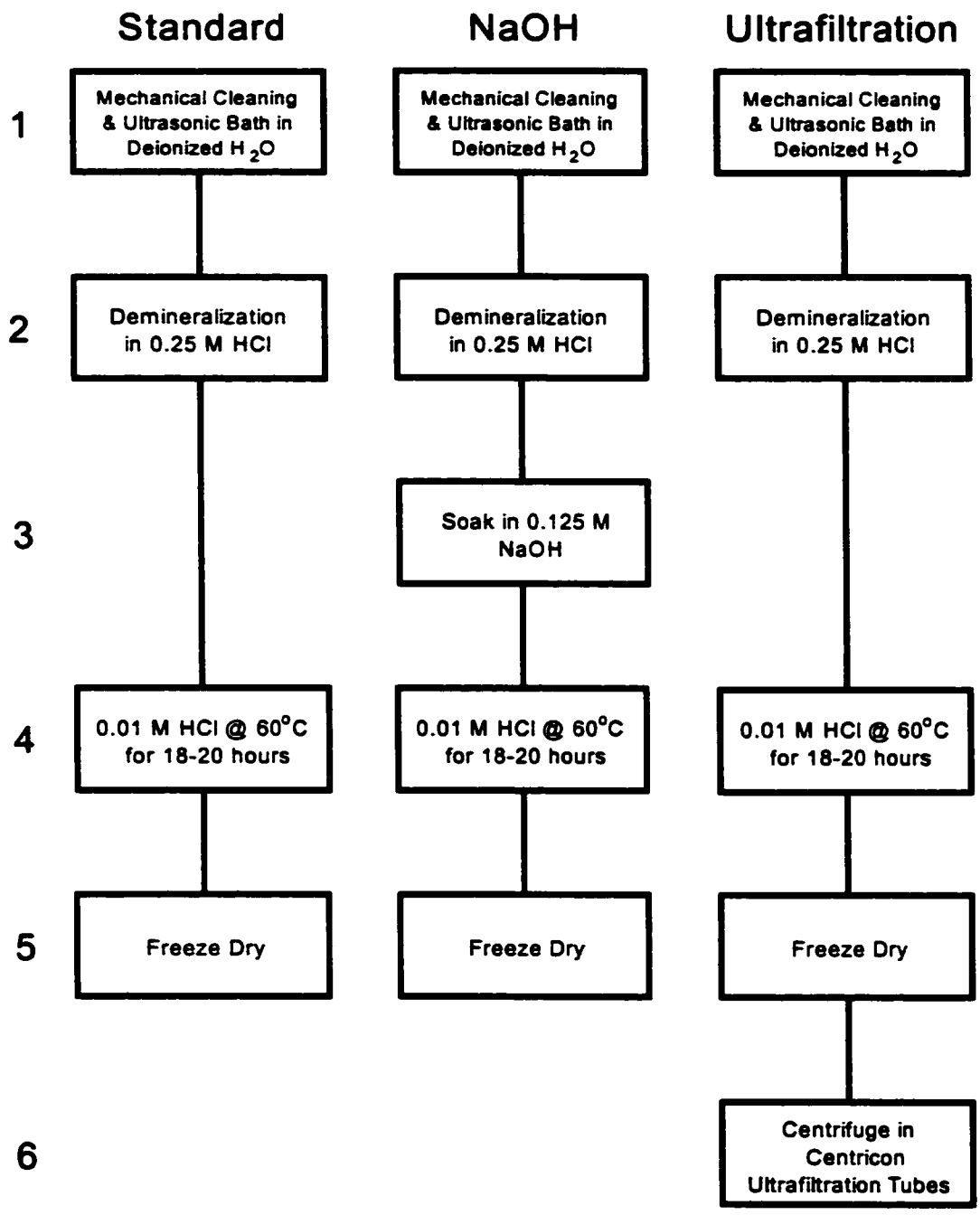


Figure 173. **Three "collagen" extraction protocols.**

concentrations, more collagen-like C and N concentrations and amino acid compositions) (Ambrose 1993; Chisholm et al. 1983a; Schoeninger et al. 1989).

Accordingly, centimeter-sized bone fragments were soaked in dilute (0.25 M) HCl at room temperature. The acid was changed several times over several days until demineralization was complete. When demineralized, the bone pseudomorph (depending on the degree of preservation) was translucent in appearance and bendable, and the acid was clear with a pH $\leq$ 1.0 maintained between changes. The samples were rinsed with deionized water to neutrality.

The NaOH protocol had a unique third step following demineralization, a 0.125 M NaOH soak. The NaOH treatment is intended to remove base-soluble lipids and humic acids. However, there is some disagreement in the literature regarding the effectiveness of this step (e.g., Ambrose 1990, 1993; Ambrose and Norr 1992; Chisholm et al. 1983a, 1993; Chisholm 1989; Häkansson 1976; Katzenberg 1989; Liden et al. 1995). NaOH treatment may reduce "collagen" yield, variably alter $\delta^{13}C$ values, and perhaps alter the amino acid composition, all without providing a demonstrably better "collagen" product. Indeed, some experiments indicate that the NaOH treatment is not effective at eliminating lipids (Liden et al. 1995) and that it is somewhat less successful in removing humic substances from "collagen" than the following step, gelatinization (van Klinken and Hedges 1995).

The fourth step involves gelatinization of the decalcified bone. This process lowers the concentration of humics and facilitates the removal of sediment particles and plant debris remaining from the first step (Longin 1971; Stafford et al. 1991). Gelatinization involves heating the decalcified bone under acidic conditions until the collagen's fibril structure denatures and it becomes soluble. Although the traditional gelatinization procedure has been to heat the demineralized bone in acidic water to 90 – 100°C for several hours (Longin 1971), more recent work has showed that acid concentrations greater than 0.01 M HCl and temperatures greater than 60°C reduce the quantity and quality of the obtained extract (Brown et al. 1988). Here, the demineralized bone chunks were placed in 100 ml teflon beakers,

filled with very dilute (0.01 M) HCl and heated to 60°C for 18 hours. This was followed by passing the gelatin solution through fine glass-fiber filters to remove all insoluble residues.

The fifth step involved drying the samples. The gelatin solution was partially evaporated at low temperature ($\approx$ 50°C), transferred to carbon-clean glass scintillation vials, and lyophilized (freeze-dried).

The sixth step in the ultrafiltration protocol is designed to remove contaminating organic substances, regardless of their particular chemistries (Brown et al. 1988). This is accomplished with Centricon-30 concentrators, which are outfitted with filters that separate low molecular weight (< 30 kiloDalton [kD]) from high molecular weight ($\geq$ 30 kD) residues in a sample. Because many humic acids are of low molecular weight (Stevenson 1982), this step serves as a gentler alternative to NaOH pretreatment for removing those contaminants. After preparing the tubes, small amounts (30 mg) of the freeze dried "collagen" were rehydrated in 0.01 M HCl. The samples were centrifuged according to the manufacturer's instructions, and the $\geq$ 30 kD fractions of the samples were dried in a rotary evaporator and weighed.

Since some published research seems to indicate that the NaOH treatment may provide little, if any, benefit for paleodiet studies, I randomly selected five individuals for the comparison between the NaOH and standard protocols. In contrast, relatively little is known about the "collagen" product obtained via the ultrafiltration protocol, and consequently, I included more specimens (between five and twenty, varying among particular tests) in my comparison of that protocol with the standard protocol. For either comparison, if the results were mixed, I was prepared to expand the number of samples. Bone from each specimen was subject to two independent replicate extractions via the standard and NaOH protocols to allow estimation of errors associated with sample

preparation and measurement. For the purposes of this study, only one of the replicates acquired via the standard protocol was subjected to ultrafiltration.

EVALUATION OF THE "COLLAGEN" PRODUCT

The only way to assess the relative effectiveness of the different protocols is to evaluate the quality of the "collagen" product. I compared sample yields, carbon and nitrogen concentrations, amino acid compositions, and stable carbon isotope ratios of "collagen" produced by the three protocols.

YIELD

"Collagen" yield (mg extract/mg dry bone) was determined for each replicate extracted via the standard and NaOH protocols. Each determination required three weight estimates (dry bone wt., empty vial wt., and vial + extract wt.), each of which was measured three times. Over the course of this study, the standard error of the yield determinations ranged from 0.000 to 0.020 %. This measurement error was negligible relative to the variation between replicates; differences in yield ranged from 0.006 to 5.331 %, with an average difference (± 1 SE) of 0.997 ± 0.060 %. Thus, to be significant, differences in "collagen" yield between extraction protocols must exceed this intra-bone variation.

The NaOH treatment has been suggested to produce a smaller "collagen" yield than that of the standard protocol (Chisholm et al. 1983a; Liden et al. 1995). Supporting such a notion, some researchers (Katzenberg 1989; Katzenberg et al. 1995) have demonstrated that a precipitated by-product of the NaOH treatment has a collagen-like amino acid composition. A paired-sample t-test, however, indicates no significant difference in "collagen" yields ($t = 1.323$; $p = .128$) among the samples considered here (Table 64). Indeed, in the two cases (samples 111 and 230) where the difference between the protocols exceeds intrabone variation, the NaOH protocol produced more "collagen," not less. These

observations should be tempered with the knowledge that sampling location affects "collagen" yield. The NaOH samples were obtained from locations in the bones interior to those subjected to the standard protocol and, thus, the amount of "collagen" available should have been greater to begin with. Although the standard deviations associated with the replicate yields tend to be larger for the NaOH than for the standard extractions, suggesting greater variation in yield, they are not significantly different (t = -1.855; p = .069). There is no reason to reject the NaOH treatment on the basis of differences in "collagen" yield.

Table 64. Comparison of the standard and NaOH protocols: average "collagen" yield (and standard deviation) for each of five samples.

	Standard Protocol		NaOH Protocol		
Sample	% Yield (avg.)	SD	% Yield (avg.)	SD	Difference
63	4.665	0.107	4.532	0.074	-0.133
78	4.891	0.208	5.850	0.284	0.959
85	7.518	0.200	6.590	0.489	-0.928
111	6.077	0.138	7.949	1.372	1.872
230	4.758	0.362	6.721	0.884	1.963

In contrast, ultrafiltration does drastically reduce the amount of material available for subsequent analyses. I found that the ultrafiltration yield was highly variable, ranging from 0.27 to 61.02% (i.e., a 30 mg sample of "collagen" resulted in 0.08 to 18.31 mg of ultrafiltered product). Factors that might account for this variation in the abundance of large molecular weight "collagen" fragments include variation among specimens in the degree of fragmentation due to peptide bond cleavage during diagenesis (Collins et al. 1995; Tuross 1991; Tuross et al. 1980) and in amounts of degradation in the post-solubilization period of the gelatinization step (Semal and Orban 1995). For the samples considered here, ultrafiltration reduces considerably the amount of "collagen" available for

subsequent analyses; further analyses will determine whether ultrafiltration actually provides a purer product.

CARBON AND NITROGEN CONCENTRATIONS

Carbon and nitrogen concentrations (weight % of "collagen") were determined using one of two automated instruments, either a Carlo Erba CHN microanalyzer or a Leeman CE440 elemental analyzer. For either machine, "collagen" samples and several acetanilide standards were weighed into silver boats and loaded into the analyzer. Approximately 1 – 3 mg of "collagen" were used; standard amounts were chosen so as to cover the range of values expected for the "collagen" samples. The analyzer combusted each sample in sequence and the resulting gases were separated chromatographically and measured. A regression line through the standards was used to estimate the elemental composition of the samples. Over the course of this study, nine samples were subject to repeat CHN analyses. Paired sample t-tests indicate they do not differ significantly at $\alpha = .05$ (%N: $t = -0.125$, $p = .902$; %C: $t = -0.555$, $p = .587$; C/N: $t = 0.726$, $p = .478$). The absolute mean differences (± 1 SE) between repeat analyses for nitrogen and carbon concentrations and C/N ratios, respectively, are 0.328 ± 0.111 %, 0.741 ± 0.281 %, and 0.303 ± 0.252. To be significant, then, differences between samples must exceed these levels of error.

Table 65 presents carbon and nitrogen concentrations and C/N ratios for "collagen" extracted by the standard, NaOH and ultrafiltration protocols. With few exceptions, these measures fall within a range consistent with modern bone collagen (%N: 5.5 – 17.3 and %C: 15.3 – 47.0 [Ambrose 1990]; C/N: 2.9 – 3.6 [DeNiro 1985]). If the NaOH protocol removes humic materials that the standard and ultrafiltration protocols fail to remove, the carbon concentrations and C/N ratios of the NaOH-produced "collagen" should be significantly less. In terms of carbon and nitrogen concentrations, samples produced by the NaOH protocol do not differ significantly from those of the standard protocol (Table 66); the C/N ratios tend to

be lower, significantly so, in samples treated with NaOH. In no case, however, does the difference in C/N ratios between standard- and NaOH-treated samples exceed measurement error.

Table 65. Carbon and nitrogen concentrations and C/N ratios for "collagen" extracted by the standard, NaOH and ultrafiltration protocols.

	Standard			NaOH			Ultrafiltration		
Sample	%N	%C	C/N[a]	%N	%C	C/N[a]	%N	%C	C/N[a]
003	14.651	41.621	3.313	--	--	--	15.527	45.052	3.384
009	14.017	39.736	3.306	--	--	--	15.860	45.408	3.339
030	14.737	42.027	3.326	--	--	--	16.225	46.111	3.314
062	12.527	37.508	3.492	--	--	--	13.700	41.584	3.541
063	14.497	41.454	3.335	13.183	37.196	3.290	14.209	41.502	3.406
078	14.238	40.650	3.329	13.738	38.873	3.300	14.122	40.659	3.358
085	12.974	36.867	3.314	13.238	37.078	3.266	--	--	--
099	14.906	41.955	3.282	--	--	--	16.712	46.692	3.258
104	15.170	42.891	3.297	--	--	--	15.742	44.850	3.322
111	15.153	43.067	3.314	13.555	38.123	3.230	15.057	45.362	3.513
153	13.359	41.495	**3.622**	--	--	--	13.845	44.031	**3.709**
154	14.771	42.616	3.365	--	--	--	13.039	45.033	**4.028**
163	10.91	38.047	**4.067**	--	--	--	7.350	43.455	**6.895**
211	13.237	37.623	3.314	--	--	--	15.311	43.853	3.340
230	13.745	39.258	3.331	13.847	39.055	3.289	--	--	--
232	13.621	38.761	3.319	--	--	--	14.843	42.886	3.370
243	14.372	41.246	3.347	--	--	--	15.283	44.243	3.376
259	13.945	40.153	3.358	--	--	--	14.599	45.142	**3.606**
421	14.481	40.409	3.254	--	--	--	12.843	44.391	**4.031**
422	14.456	40.629	3.278	--	--	--	14.650	45.912	**3.655**
424	14.527	41.489	3.331	--	--	--	14.132	45.288	**3.737**
426	14.306	40.907	3.335	--	--	--	15.055	46.204	3.579

[a] Samples with C/N ratios outside the range of modern collagen, 2.9 – 3.6, are in boldface.

Samples treated by ultrafiltration do not differ significantly from standard preparations in nitrogen concentration, but the carbon concentrations and, consequently, C/N ratios are significantly higher (Table 66). Indeed, 33.3% (7/21) of the ultrafiltered samples (as compared to 9.5% [2/21] of the standard samples) have C/N ratios outside the range of modern collagen. This could reflect a greater proportion of high molecular weight noncollagenous proteins in the ultrafiltered samples and/or, perhaps to a lesser extent, exogenous materials (e.g., humics) that have formed strong bonds with large molecular weight residues. Noncollagenous proteins have slightly higher C/N ratios than collagen whereas humic substances have substantially greater C/N ratios (Masters 1987). Radiocarbon determinations indicate that the contribution of the latter to ultrafiltered samples is not significant in some cases, at least (Brown et al. 1988).

Table 66. Comparison of carbon and nitrogen concentrations and C/N ratios for the standard protocol versus the NaOH and the ultrafiltration protocols.

		% Nitrogen		% Carbon[a]		C/N Ratio[a]	
	df	*t*	*p*	*t*	*p*	*t*	*p*
NaOH	4	-1.642	.176	-2.104	.103	**-12.164**	**<.001**
Ultrafiltration	19	-1.012	.324	**-9.468**	**<.001**	**-2.180**	**.042**

[a] Significant differences at $\alpha = .05$ are in boldface.

AMINO ACID COMPOSITION

At face value, results of amino acid evaluations of different extraction protocols have been mixed. Katzenberg (1989; Katzenberg et al. 1995) did not find differences in amino acid composition between samples treated with NaOH and those not treated. In contrast, Liden et al. (1995) did identify significant differences in amino acid composition of "collagen" from bones treated with NaOH and those not. While this may reflect variation in "collagen" preservation and/or extraction, the more obvious factor lies in how these researchers defined "different." While

Katzenberg relied on visual comparison of the patterns of amino acid abundances, Liden et al. appealed to statistical testing. As Liden et al. note, however, their statistical tests are suspect because amino acid abundances, quantified as residues/1000, are closed arrays. Visual examination of their data does not support the notion of different amino acid compositions.

For amino acid analysis, 0.2 – 0.4 mg of "collagen" were placed in an ampule with 6.0 M HCl, a crystal of phenol, mercaptoethanol, and a known amount of norleucine standard. The ampule was evacuated and flushed with argon repeatedly, sealed, and hydrolyzed at 115°C for twenty hours. Following evaporation and solubilization in lithium buffer, the samples were loaded onto a model 7300 Beckman Amino Acid Analyzer with System Gold Software for amino acid analysis. The standard error associated with repeat analyses is approximately 2 percent.

Figure 174 and Table 67 present the amino acid compositions of five samples of "collagen" from the standard and NaOH protocols and compare them to the composition of modern human bone collagen (Woodhead-Galloway 1980). For the archaeological extracts, column height reflects the mean abundance for each amino acid; error bars show the minimum and maximum values obtained. Both kinds of extracts closely mimic the composition of modern collagen and it would be very difficult to say that the result of one extraction protocol is more collagen-like than the other. Although, for any given individual, there are differences between the two extraction protocols in the compositions of "collagen," the differences are not systematic, as might be expected if the NaOH treatment were biasing the amino acid composition of "collagen." However, if the NaOH treatment were providing a significantly purer "collagen," those samples should have a greater total amino acid weight % than the standard extracts. Instead, as Table 68 shows, they had a significantly lower concentration of amino acids ($t = 2.836$; $p = .024$). This suggests that there are greater levels of contamination in the NaOH-treated samples;

because the NaOH-treated samples did not also have higher carbon concentrations, the contamination is probably inorganic.

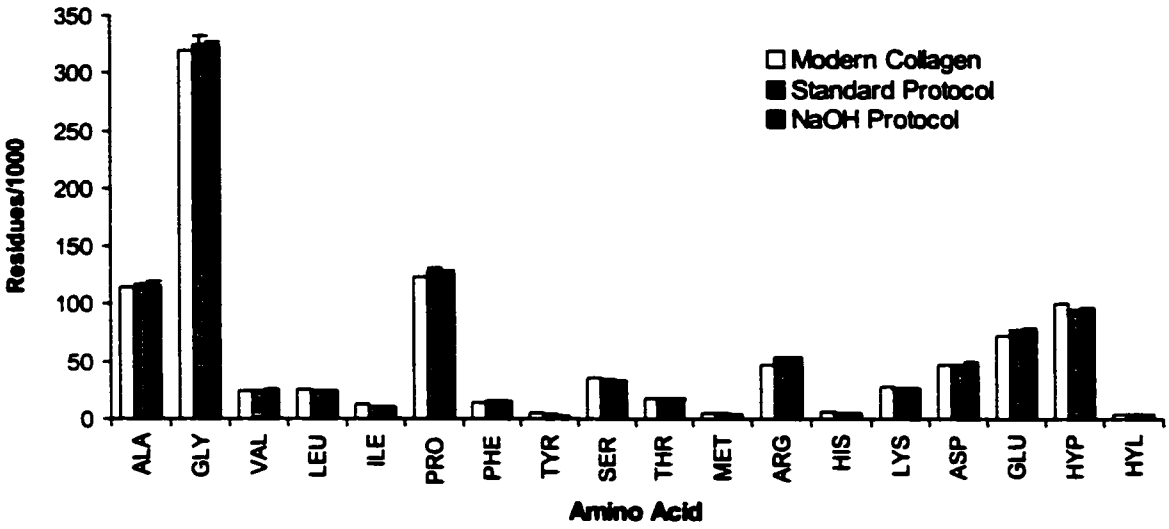


Figure 174. **Amino acid composition of modern human bone collagen and "collagen" from the standard and NaOH protocols.** Error bars indicate range of values obtained; such information is lacking from reported modern data (Woodhead-Galloway 1980). ALA, alanine; GLY, glycine; VAL, valine; LEU, leucine; ILE, isoleucine; PRO, proline; PHE, phenylalanine; TYR, tyrosine; SER, serine; THR, threonine; MET, methionine; ARG, arginine; HIS, histidine; LYS, lysine; ASP, aspartic acid; GLU, glutamic acid; HYP, hydroxyproline; HYL, hydroxylysine.

The amino acid composition of the "collagen" products of the ultrafiltration process have not been examined previously. In Figure 175 and Table 69, the amino acid compositions of six samples of "collagen" from the standard and ultrafiltration protocols are compared to the composition of modern human bone collagen (Woodhead-Galloway 1980). As in the previous comparison, column height reflects the mean abundance and error bars indicate the maximum and minimum values obtained. The ≥ 30 kD "collagen" produced by ultrafiltration is more variable in amino acid composition than that of the standard protocol, and its entire amino acid profile is less collagen-like. A significantly purer "collagen" might be

Table 67. Amino acid compositions of modern collagen and "collagen" extracted via the standard (Std) and NaOH protocols. Amino acid abbreviations detailed in Figure 174 caption.

	Modern[a]	063		078		085		111		230	
		Std	NaOH	Std	NaOH	Std	NaOH	Std	NaOH	Std	NaOH
ALA	114	117	120	117	115	113	115	115	117	113	113
GLY	319	320	322	323	322	333	325	325	323	322	328
VAL	24	24	23	23	25	24	24	24	25	24	24
LEU	25	23	23	24	24	23	23	23	23	24	24
ILE	13	10	10	10	11	10	10	10	10	10	10
PRO	123	128	124	129	127	126	128	130	126	130	125
PHE	14	15	15	15	14	14	13	13	14	13	14
TYR	5	3	1	2	2	3	3	2	2	3	3
SER	36	33	33	34	34	33	33	33	32	34	33
THR	18	18	18	18	17	18	17	17	17	18	17
MET	5	5	2	4	4	4	3	5	3	4	3
ARG	47	53	50	51	53	52	53	52	52	53	53
HIS	6	4	4	4	4	5	4	4	4	5	5
LYS	28	27	26	25	25	26	27	25	26	26	26
ASP	47	46	50	47	46	47	46	45	47	47	47
GLU	72	75	79	74	77	73	75	77	78	76	76
HYP	100	94	96	95	96	92	95	95	97	94	95
HYL	4	4	4	4	4	4	4	3	4	4	4
Σ	1000	999	1000	999	1000	1000	998	998	1000	1000	1000

[a] Source: (Woodhead-Galloway 1980).

Table 68. Total amino acid weight (%) in "collagen" from the standard and NaOH protocols.

	63	78	85	111	230
Standard	72.921	76.005	64.336	77.104	75.624
NaOH	59.311	66.381	65.640	67.593	70.845

expected from the ultrafiltration protocol; many of the ultrafiltered samples did have a greater total amino acid weight % than the standard extracts (Table 70), but the difference was not significant (t = -1.873; p = .060). The < 30 kD byproduct of the ultrafiltration process also contains a variably collagen-like distribution of amino acids, demonstrating that "collagen" is among the low molecular weight fragments removed. As might be expected, the total amino acid weight % of the < 30 kD fraction is highly variable, ranging from 28 to 85%.

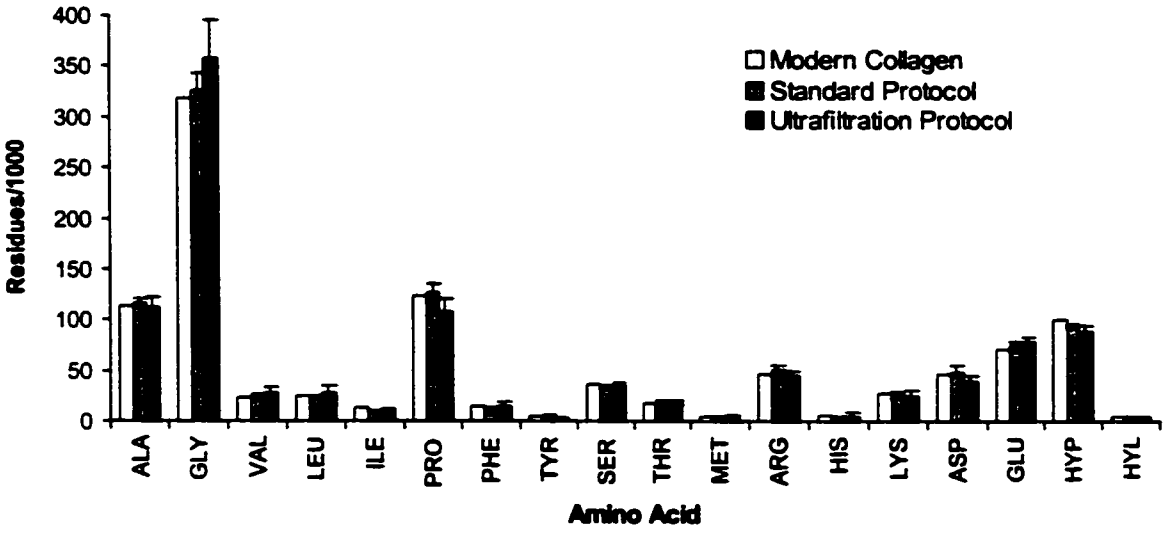


Figure 175. **Amino acid composition of modern human bone collagen and "collagen" from the standard and ultrafiltration protocols.** Error bars indicate range of values obtained; such information is lacking from reported modern data (Woodhead-Galloway 1980). ALA, alanine; GLY, glycine; VAL, valine; LEU, leucine; ILE, isoleucine; PRO, proline; PHE, phenylalanine; TYR, tyrosine; SER, serine; THR, threonine; MET, methionine; ARG, arginine; HIS, histidine; LYS, lysine; ASP, aspartic acid; GLU, glutamic acid; HYP, hydroxyproline; HYL, hydroxylysine.

Although the CHN data were consistent with the notion that the ultrafiltered "collagen" contained higher proportions of noncollagenous proteins, the amino acid compositions do not support that idea. In particular, the ≥ 30 kD "collagen" tends to have higher glycine (GLY) and lower aspartic acid (ASP) contents than modern collagen, neither of which is a feature of noncollagenous

Table 69. Amino acid compositions of modern collagen and "collagen" extracted via the standard (Std) and the ultrafiltration (UF) protocols. The UF samples are the ≥ 30 kD size fraction. Amino acid abbreviations are detailed in Figure 175 caption.

	Modern[a]	062		101		104		111		153		163	
		Std	UF	Std	UF	Std	UF	Std	UF	Std	UF	Std	UF
ALA	114	113	110	115	109	115	110	115	106	118	114	121	122
GLY	319	343	380	317	332	324	312	325	395	318	372	326	355
VAL	24	26	29	26	29	24	33	24	25	26	26	25	26
LEU	25	24	28	24	28	24	35	23	24	23	24	22	23
ILE	13	11	11	10	11	10	10	10	10	10	10	10	10
PRO	123	105	63	135	121	127	116	130	114	132	117	130	114
PHE	14	13	14	13	15	13	18	13	12	12	11	14	12
TYR	5	6	1	2	3	1	3	2	0	3	3	2	0
SER	36	34	37	32	35	33	35	33	32	33	34	33	37
THR	18	20	20	18	18	17	20	17	16	18	18	17	18
MET	5	4	4	3	5	5	5	5	3	4	3	4	2
ARG	47	46	50	55	48	55	46	52	42	53	43	46	40
HIS	6	3	3	4	5	4	9	4	3	3	3	2	3
LYS	28	26	28	27	25	29	31	25	22	25	22	23	24
ASP	47	56	42	47	39	45	45	45	34	48	33	50	45
GLU	72	70	80	74	82	77	81	77	71	74	75	79	80
HYP	100	96	94	94	91	94	87	95	86	95	89	94	86
HYL	4	5	4	4	4	4	3	3	4	3	4	3	3
Σ	1000	1001	998	1000	1000	1001	999	998	999	998	1001	1001	1000

[a] Source: (Woodhead-Galloway 1980).

Table 70. Total amino acid weight (%) in "collagen" from standard and ultrafiltration protocols.

	062	101	104	111	153	163
Standard	42.882	64.221	58.167	77.104	66.005	42.670
Ultrafiltration	76.640	58.263	76.931	92.434	82.975	35.830

proteins, or of degraded "collagen" in general. Why this is the case is unclear. Perhaps there is bias in the way "collagen" degrades, such that some bonds are broken more easily than others and thus, some parts of the amino acid sequence are more likely to be fragmented. Those fragments, still retained during standard extraction protocols, would be more likely to be removed during the ultrafiltration process, and the end result would be differing amino acid compositions between standard-treated and ultrafiltered samples. Clearly, more work is needed to understand why the ultrafiltered samples tend to have amino acid compositions so different from modern collagen and "pre-ultrafiltered collagen" extracted via the standard protocol.

STABLE CARBON ISOTOPE ANALYSIS

Comparing stable carbon isotope values between "collagen" samples obtained via the different protocols also permits evaluation of the relative success of those protocols in removing contaminants. In a C_3-dominated terrestrial environment, like the Eastern Woodlands, soil humic substances will have negative $\delta^{13}C$ values; consequently, their removal should increase the $\delta^{13}C$ value of "collagen," particularly when it is enriched. As a test, Katzenberg et al. (1995) compared "collagen" extracted with and without NaOH treatment for eleven individuals from Ontario. A one-tailed paired-sample *t*-test evaluating her results does not find them statistically different at $\alpha = 0.05$ ($t = -1.598$; $p = .071$). Thus, the extraction protocol did not have a significant impact on the $\delta^{13}C$ of those "collagen" samples.

For this study, ten mg of "collagen" from each replicate were weighed into a clean Vycor boat along with manganese dioxide, copper oxide, and silver wire. Each boat was placed in a clean Vycor ampule, evacuated, and sealed before being combusted at 900°C for one hour. Carbon dioxide in the combusted samples was purified cryogenically prior to isotopic measurement on a Micromass 903 mass spectrometer.

Error introduced during sample preparation and measurement must be estimated before differences in the $\delta^{13}C$ values between extraction protocols can be assessed. One source of measurement error is associated with the mass spectrometer. Two measurements were obtained for each "collagen" CO_2 sample analyzed; the standard deviation of those duplicate measurements ranged from 0.00 to 0.13 ‰. This standard deviation reflects error associated with obtaining and measuring separate aliquots of the same CO_2 source gas. Fifty-one measurements of a cellulose standard over the duration of the analysis produced a standard deviation of 0.058 ‰ and a standard error of 0.008 ‰. The variation included within this error term reflects both the mass spectrometer and CO_2 production.

Error associated with mass spectrometry, sample preparation, and sample homogeneity can be estimated by comparing measurements for replicate "collagen" samples from the same bone. The mean difference (± 1 SE) in $\delta^{13}C$ values between each pair of archaeological replicates in this study is -0.015 ± 0.015 ‰. A paired sample t-test showed no significant differences between sample replicates at $\alpha = 0.05$ ($t = -1.008$; $p = .157$). When the measurements of a pair of replicates differed by more than 0.25 ‰, a third independent extraction was obtained. A third extract was produced for 27 individuals over the duration of this research. When the $\delta^{13}C$ value of the third replicate was midway between or well outside the range of the first two measurements, all three were averaged to provide an estimate of $\delta^{13}C$ for the individual; when it was in close agreement (< 0.25 ‰) with one of the first pair, those two were averaged (with the distant third considered a blunder). It is important to note that measuring replicates of each skeletal sample is atypical; yet, if it is not undertaken, there is no way to recognize inaccurate determinations.

Table 71 and Figure 176 present the results of isotopic analyses of "collagen" samples produced by the standard and NaOH extraction protocols. No error bars are shown in Figure 176 because the errors are equal to or smaller than the point size. It is apparent that, although most of the NaOH "collagen" samples

are slightly enriched (t = -2.6949; p = .054), there is little difference in the $\delta^{13}C$ values between the two extraction protocols. The difference between samples extracted via the two protocols is less than the error allowed between replicates extracted by the same technique. For the kinds of samples analyzed here, the NaOH treatment has no significant impact on $\delta^{13}C$ values.

Table 71. Mean $\delta^{13}C$ and standard error of sample replicates of "collagen" from the standard (S) and NaOH (N) protocols. Data are in units ‰ PDB.

Sample		Rep. 1	SE 1	Rep. 2	SE 2	Rep. 3	SE 3	Average	SE
063	S	-13.57	0.04	-13.26	0.05	-13.23	0.01	-13.25	0.04
063	N	-13.29	0.01	-13.26	0.03	--	--	-13.28	0.03
078	S	-20.52	0.09	-20.59	0.02	--	--	-20.56	0.08
078	N	-20.47	0.00	-20.41	0.01	--	--	-20.44	0.04
085	S	-8.93	0.02	-9.00	0.04	--	--	-8.97	0.06
085	N	-8.71	0.02	-8.86	0.00	--	--	-8.79	0.11
111	S	-20.76	0.02	-20.74	0.02	--	--	-20.75	0.02
111	N	-20.59	0.01	-20.7	0.02	--	--	-20.65	0.08
230	S	-10.32	0.03	-10.42	0.04	--	--	-10.37	0.08
230	N	-10.19	0.03	-10.07	0.00	--	--	-10.13	0.08

Differences in the isotopic composition of "collagen" samples extracted by the standard and ultrafiltration protocols are greater (Table 72, Figure 177). In both exhibits, the $\delta^{13}C$ values are from matching replicates of "collagen" from the standard and ultrafiltration protocols (i.e., the $\delta^{13}C$ value for each standard "collagen" sample is from the same replicate which was subsequently purified via ultrafiltration). Again, if ultrafiltration does remove humic substances, thus providing a purer "collagen," in this C_3 terrestrial environment we would expect more positive $\delta^{13}C$ values to result. Although a t-test indicates the two extracts differ significantly (t = 2.595; p = .027), the $\delta^{13}C$ values of ultrafiltered "collagen" tend to be more negative than those from the standard protocol rather than being more positive.

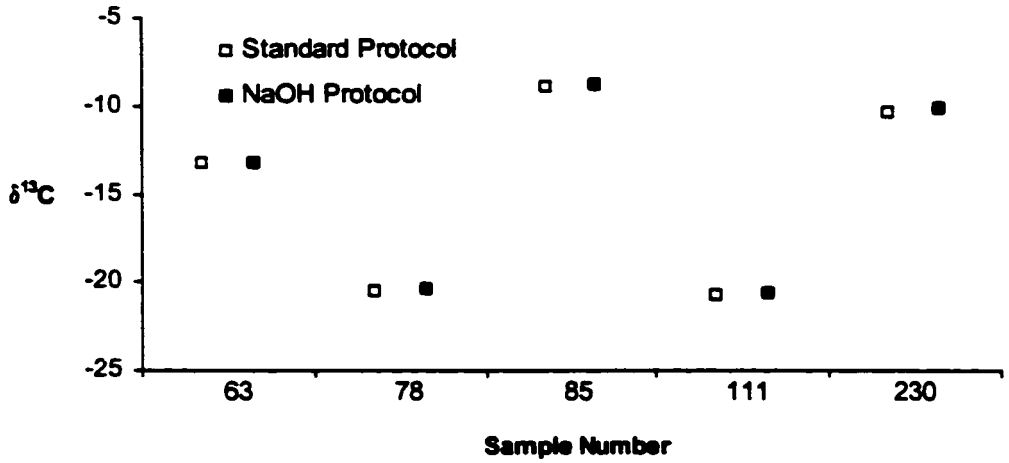


Figure 176. **$\delta^{13}C$ values of "collagen" from the standard and NaOH extraction protocols.**

There is an additional consideration about the quality of "collagen" obtained with the ultrafiltration protocol: precision. Remember that the mean difference (± 1 SE) in $\delta^{13}C$ values between "collagen" replicates extracted with the standard protocol was -0.015 ± 0.015 ‰; the standard deviation was 0.229 ‰. For ten replicate samples of "collagen" acquired via ultrafiltration (this includes unpublished data obtained during the course of research on specimens from southeast Missouri), the mean difference (± 1 SE) in $\delta^{13}C$ was 0.201 ± 0.464 ‰, with a standard deviation of 1.392 ‰. Thus, there is considerably greater isotopic variation between ≥ 30 kD replicates than there is between replicates acquired with the standard protocol. To achieve the same level of precision would require many more replicates at greater cost.

Table 72. Comparison of $\delta^{13}C$ values for "collagen" from the standard and ultrafiltration (UF) protocols. Data are in units ‰ PDB.

	Standard		≥ 30 kD UF	
	$\delta^{13}C$	SE	$\delta^{13}C$	SE
003	-8.61	0.00	-8.97	0.04
009	-9.06	0.03	-9.27	0.02
030	-8.21	0.01	-8.53	0.02
062	-11.34	0.00	-11.17	0.02
099	-20.65	0.09	-20.56	0.02
111	-20.76	0.02	-20.83	0.05
153	-20.92	0.00	-21.13	0.01
243	-9.46	0.01	-9.81	0.03
259	-20.26	0.00	-20.48	0.02
422	-7.68	0.01	-9.00	0.01
426	-7.70	0.00	-8.39	0.03

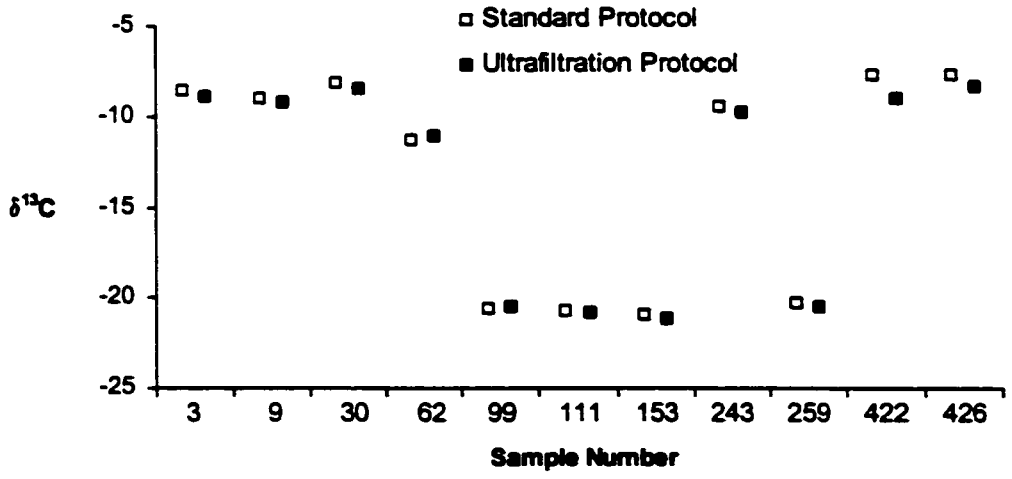


Figure 177. **$\delta^{13}C$ values of "collagen" obtained via the standard and ultrafiltration protocols.**

"COLLAGEN" QUALITY AND EXTRACTION PROTOCOL

Several observations can be made about the relative merit of the three different extraction protocols on the quality of "collagen" products:

1. "Collagen" yield does not differ between the NaOH and standard protocols. The ultrafiltration protocol substantially reduces the amount of "collagen" available for subsequent analyses.

2. Elemental composition (%N and %C) does not differ between the NaOH and standard protocols; although C/N ratios tend to be smaller for NaOH-treated samples, the differences do not exceed intrabone variation and measurement error. Ultrafiltered "collagen" has significantly greater %C and C/N ratios than the standard extract.

3. Amino acid composition does not differ between the NaOH and standard protocols; however, the NaOH-treated "collagen" has lower concentrations of amino acids. The ultrafiltered $\geq$ 30 kD "collagen" is more variable than the standard extract in terms of amino acid composition, but it also contains a higher proportion of protein.

4. Differences in the isotopic composition of "collagen" from the NaOH and standard protocols are generally in the direction expected if NaOH was removing contaminating humic materials, but the differences do not exceed measurement error. Differences in the isotopic composition of ultrafiltered versus standard "collagen" tend to be opposite the expected direction, and precision is much less for the $\geq$ 30 kD than for standard "collagen."

From these observations I conclude that neither the NaOH nor the ultrafiltration protocols appear to produce a significantly better product than the standard HCl protocol, although this runs counter to most sentiment in the literature. Accordingly, "collagen" for this research was extracted from archaeological bones using the standard protocol. Eliminating the extra steps that the other two protocols require was more efficient for processing the large number of samples necessitated by the research question and the results are comparable with previous work.

APPENDIX E: METEOROLOGICAL STATION INVENTORY

Table 73. List of meteorological stations with long-term historic weather records used to examine geographic patterns in climatic parameters.

STATION #	LAT	LONG	ELEV	STATE	STATION NAME
120177	40.1	-85.72	845	IN	ANDERSON SEWAGE PLANT
120200	41.63	-84.98	1010	IN	ANGOLA
120676	40.67	-84.95	860	IN	BERNE
120784	39.17	-86.52	825	IN	BLOOMINGTON IN UNIV
121030	39.42	-85.02	760	IN	BROOKVILLE
121229	39.87	-85.18	999	IN	CAMBRIDGE CITY
121425	38.37	-85.68	525	IN	CHARLESTOWN ORD PLT
121747	39.2	-85.92	621	IN	COLUMBUS
121873	39.97	-86.93	762	IN	CRAWFORDSVILLE 5S
122149	40.62	-86.67	560	IN	DELPHI 3NNE
123418	41.57	-85.83	805	IN	GOSHEN COLLEGE
123513	39.63	-86.85	860	IN	GREENCASTLE 1SE
123527	39.78	-85.75	865	IN	GREENFIELD
124008	41.55	-87.28	640	IN	HOBART 2WNW
124181	40.85	-85.5	725	IN	HUNTINGTON
124837	41.6	-86.72	810	IN	LAPORTE
125237	38.73	-85.4	455	IN	MADISON SEWAGE PLANT
125337	40.57	-85.67	790	IN	MARION 2N
126001	37.95	-87.88	415	IN	MOUNT VERNON
126580	38.88	-86.55	650	IN	OOLITIC PURDUE EXP FM
126705	38.55	-86.48	560	IN	PAOLI
127125	38.35	-87.58	480	IN	PRINCETON 1W
127298	40.93	-87.15	650	IN	RENSSELAER
127482	41.07	-86.22	770	IN	ROCHESTER
127522	39.77	-87.23	690	IN	ROCKVILLE
127646	39.6	-85.45	955	IN	RUSHVILLE SEWAGE PL
127755	38.62	-86.08	800	IN	SALEM
127875	38.7	-85.77	550	IN	SCOTTSBURG
127935	38.98	-85.9	573	IN	SEYMOUR 2N
128036	38.67	-86.8	550	IN	SHOALS HIGHWAY 50 BRIDGE
129080	38.75	-85.07	470	IN	VEVAY
129113	38.73	-87.5	450	IN	VINCENNES 5NE
129253	38.67	-87.18	485	IN	WASHINGTON
129511	41.25	-87.08	655	IN	WHEATFIELD 4NNW

Table 73 (continued).

STATION #	LAT	LONG	ELEV	STATE	STATION NAME
129557	40	-86.35	935	IN	WHITESTOWN
129670	41.02	-86.58	690	IN	WINAMAC 2SSE
150254	38.45	-82.62	560	KY	ASHLAND
150619	37.57	-84.3	1070	KY	BEREA COLLEGE
150909	36.97	-86.43	528	KY	BOWLING GREEN FAA AP
152791	38.12	-83.55	680	KY	FARMERS 2S
153028	38.23	-84.87	500	KY	FRANKFORT LOCK 4
153430	37.25	-85.5	590	KY	GREENSBURG
153994	36.83	-87.5	590	KY	HOPKINSVILLE
154703	37.52	-86.3	620	KY	LEITCHFIELD 2N
155389	36.6	-83.73	1175	KY	MIDDLESBORO
156091	37.77	-87.15	405	KY	OWENSBORO 3W
157324	38.2	-85.2	730	KY	SHELBYVILLE 1E
158709	36.73	-84.17	1000	KY	WILLIAMSBURG
158714	38.65	-84.62	940	KY	WILLIAMSTOWN 3NW
180470	39.28	-76.62	14	MD	BALTIMORE WSO CITY
181385	38.57	-76.07	5	MD	CAMBRIDGE WATER TRMT PLANT
181750	39.22	-76.07	40	MD	CHESTERTOWN
181995	38.98	-76.95	90	MD	COLLEGE PARK
182282	39.63	-78.75	730	MD	CUMBERLAND 2
182523	38.88	-75.8	50	MD	DENTON 2E
183675	38.97	-76.8	150	MD	GLENN DALE BELL STN
185111	39.1	-76.9	400	MD	LAUREL 3W
185985	39.27	-75.87	30	MD	MILLINGTON 1SE
186620	39.4	-79.4	2420	MD	OAKLAND 1SE
186770	38.68	-76.67	160	MD	OWINGS FERRY LANDING
186915	38.33	-76.42	38	MD	PATUXENT RIVER
187330	38.22	-75.68	20	MD	PRINCESS ANNE
187806	38.72	-76.18	10	MD	ROYAL OAK 2SSW
188000	38.37	-75.58	10	MD	SALISBURY
189440	39.55	-76.97	765	MD	WESTMINSTER POLICE BRKS
189750	39.33	-76.87	460	MD	WOODSTOCK
331072	40.82	-82.97	955	OH	BUCYRUS
331152	40.27	-81	1260	OH	CADIZ
331541	41.05	-81.93	1180	OH	CHIPPEWA LAKE
331592	39.62	-82.95	673	OH	CIRCLEVILLE
331890	40.25	-81.87	760	OH	COSHOCTON WPC PLANT
332119	40.28	-83.07	868	OH	DELAWARE
332791	41.05	-83.67	768	OH	FINDLAY WPCC
333375	40.1	-84.65	1024	OH	GREENVILLE WATER PLANT

Table 73 (continued).

STATION #	LAT	LONG	ELEV	STATE	STATION NAME
333758	39.2	-83.62	1100	OH	HILLSBORO
333780	41.3	-81.15	1230	OH	HIRAM
334189	40.65	-83.6	995	OH	KENTON
335041	39.65	-81.85	660	OH	MCCONNELLSVILLE LOCK 7
335297	40.55	-81.92	819	OH	MILLERSBURG
335315	40.72	-80.9	1145	OH	MILLPORT 2NW
335669	41.37	-84.15	682	OH	NAPOLEON
336118	41.27	-82.62	670	OH	NORWALK WWTP
336196	41.27	-82.22	816	OH	OBERLIN
336600	39.83	-81.92	1020	OH	PHILO 3SW
336781	38.75	-82.88	540	OH	PORTSMOUTH-SCIOTOVILLE
338313	41.12	-83.17	740	OH	TIFFIN
338534	40.83	-83.28	854	OH	UPPER SANDUSKY
338552	40.1	-83.78	1000	OH	URBANA WWTP
338769	41.2	-80.82	900	OH	WARREN 3S
338822	41.52	-84.15	750	OH	WAUSEON WATER PLANT
338830	39.12	-82.98	560	OH	WAVERLY
339312	40.78	-81.92	1020	OH	WOOSTER EXP STN
360106	40.65	-75.43	387	PA	ALLENTOWN WSO AP
361354	39.93	-77.63	640	PA	CHAMBERSBURG 1ESE
362537	39.8	-77.27	520	PA	EISENHOWER NATL HIST SITE
362682	42.08	-80.18	732	PA	ERIE WSO AP
363028	41.38	-79.82	990	PA	FRANKLIN
363056	41.02	-75.9	1900	PA	FREELAND
363526	41.42	-80.37	1130	PA	GREENVILLE 2NE
363699	40.22	-76.85	340	PA	HARRISBURG CAPITAL CITY
364385	40.33	-78.92	1214	PA	JOHNSTOWN
365915	41.83	-75.87	1560	PA	MONTROSE
366233	41.02	-80.37	825	PA	NEW CASTLE 1N
366689	40.8	-75.62	410	PA	PALMERTON
367322	40.42	-75.93	360	PA	READING 4NNW
367477	41.42	-78.75	1360	PA	RIDGWAY
367931	40.77	-76.87	420	PA	SELINSGROVE 2S
368449	40.8	-77.87	1170	PA	STATE COLLEGE
368596	41	-75.18	480	PA	STROUDSBURG
368905	41.75	-76.42	750	PA	TOWANDA 1ESE
369050	39.92	-79.72	956	PA	UNIONTOWN 1NE
369298	41.85	-79.15	1210	PA	WARREN
369408	41.7	-77.27	1860	PA	WELLSBORO 4SSE
369464	39.97	-75.63	450	PA	WEST CHESTER 1W

Table 73 (continued).

STATION #	LAT	LONG	ELEV	STATE	STATION NAME
369728	41.25	-76.92	527	PA	WILLIAMSPORT WSO AP
369933	39.92	-76.75	390	PA	YORK PUMP STATION 3SSW
440766	37.08	-80.4	1900	VA	BLACKSBURG 3SE
440993	37.7	-78.3	225	VA	BREMO BLUFF
441209	37.08	-81.33	3300	VA	BURKES GARDEN
441593	38.03	-78.52	870	VA	CHARLOTTESVILLE 2W
442208	38.45	-78.93	1400	VA	DALE ENTERPRISE
442245	36.58	-79.38	410	VA	DANVILLE
442941	37.33	-78.38	450	VA	FARMVILLE 2N
443192	38.32	-77.45	90	VA	FREDERICKSBURG NATIONAL PARK
444101	37.3	-77.3	40	VA	HOPEWELL
444128	38	-79.83	2236	VA	HOT SPRINGS
444876	37.78	-79.43	1060	VA	LEXINGTON
444909	39.12	-77.72	500	VA	LINCOLN
446139	36.9	-76.2	24	VA	NORFOLK WSO AP
446626	36.75	-83.05	1510	VA	PENNINGTON GAP
446712	38.22	-78.12	520	VA	PIEDMONT RESEARCH STN
447338	37	-79.9	1232	VA	ROCKY MOUNT
448062	38.08	-79.08	1390	VA	STAUNTON SEWAGE PLANT
449151	37.3	-76.7	70	VA	WILLIAMSBURG 2N
449263	38.9	-78.47	660	VA	WOODSTOCK 2NE
461220	38.98	-80.22	1455	WV	BUCKHANNON
461330	39.2	-81.15	700	WV	CAIRO 3ENE N BEND SP
463353	37.37	-81.55	1430	WV	GARY
463544	38.93	-80.82	720	WV	GLENVILLE 1ENE
465224	37.85	-80.4	2303	WV	LEWISBURG 3N
465626	39.53	-80.5	1100	WV	MANNINGTON 8WNW
465707	39.4	-77.98	537	WV	MARTINSBURG FAA AIRPORT
466867	39.1	-79.67	1770	WV	PARSONS 1NE
467001	38.62	-80.18	3499	WV	PICKENS 4SSE
468384	38.8	-81.35	740	WV	SPENCER 1SE
469368	40.28	-80.62	660	WV	WELLSBURG WATER TRMT PLANT
469605	37.67	-82.28	670	WV	WILLIAMSON
469683	38.53	-81.92	571	WV	WINFIELD LOCKS

APPENDIX F: BONE SAMPLES ANALYZED AND RESULTS

Table 74. List of 251 skeletal samples analyzed for this research. Sex and age information taken from published reports and laboratory forms.

#	Source[1]	Site Name	Site #	Acc/Cat/Bur/Fea	Ele.[2]	Sex	Age
001	CaMNH	Bunola	36AL4	E545	Tib	F	30 ± 5
002	CaMNH	Bunola	36AL4	E2050	Fib	F	54 ± 5
003	CaMNH	Bunola	36AL4	FC2210	Fib	M	37 ± 5
004	CaMNH	Bunola	36AL4	FC2369	Fib	F	Adult
005	CaMNH	Bunola	36AL4	FC5070	Fib	F	Adult
006	CaMNH	Bunola	36AL4	FC5074	Fib	M	57 ± 5
007	CaMNH	Bunola	36AL4	FC5079	Fib	M	Adult
008	CaMNH	Bunola	36AL4	FC5085	Fib	M	29 ± 5
009	CaMNH	Middle Site Island	36AL13	FCC476	Fib	F	27 ± 5
010	CaMNH	McKees Rocks Vill.	36AL16	FC4092	Fib	F	30 ± 5
011	CaMNH	McKees Rocks Vill.	36AL16	FC4097	Fib	--	--
012	CaMNH	McJunkin	36AL17	FC475	Fib	M	27 ± 5
013	CaMNH	Rinehart	--	Bur 1	Fib	M	42 ± 5
014	CaMNH	Godwin-Portman	36AL39	FC86/89	Fib	M	Adult
015	CaMNH	Godwin-Portman	36AL39	FC4421	Fib	F	22 ± 2
016	CaMNH	Godwin-Portman	36AL39	FC5743	Fib	M	32 ± 5
017	CaMNH	Portman	36AL40	FC E2047	Fib	M	42 ± 5
018	CaMNH	Barn	36AL53	FC3904(1)	Fib	M	Adult
019	CaMNH	Drew	36AL62	FC E72	Fib	F	27 ± 3
020	CaMNH	farm near N. Vandergrift	36AR?	FC3882	Fib	M	25 ± 5
021	CaMNH	Bonnie Brook	36BT43	FC8338	Fem	F	22 ± 3
022	CaMNH	A. M. Byers	36BV?	FC3777	Fib	M	Adult
023	CaMNH	Shippenport	36BV4	FC188	Rad	M	21 ± 3
024	CaMNH	Ohioview	36BV9	FC3859	Fib	F	--
025	CaMNH	Ohioview	36BV9	FC4381	Tib	M	Adult
026	CaMNH	Rochester	36BV80	FC3763(2)	Hum	M	32 ± 3
027	CaMNH	Pinnacle	36EL49	FC7684	Tib	F	33 ± 5

Table 74 (continued).

#	Source[1]	Site Name	Site #	Acc/Cat/Bur/Fea	Ele.[2]	Sex	Age
028	CaMNH	Reservoir	36FA7	FC E2	Fib	M	45 ± 5
029	CaMNH	Elliot	36FA14	FC E18	Fib	F	25 ± 5
030	CaMNH	Francis	36FA15	E-23	Fib	F	45 ± 5
031	CaMNH	Fuller's Hill	36FA17	E-27	Fib	M	47 ± 5
032	CaMNH	Fuller's Hill	36FA17	E-32	Fib	M	32 ± 5
033	CaMNH	Campbell Farm	36FA26	4899	Fib	F	42 ± 5
034	CaMNH	Varner	36GR1	2144	Fib	M	37 ± 5
035	CaMNH	Varner	36GR1	2156	Fib	F	33 ± 3
036	CaMNH	Varner	36GR1	2157	Fib	F	45 ± 5
037	CaMNH	Varner	36GR1	2158	Fib	M	45 ± 5
038	CaMNH	Hartley	36GR23	KB1	Fib	F	37
039	CaMNH	Hartley	36GR23	4562(2)	Fib	F	32 ± 5
040	CaMNH	Johnston	36IN2	821	Fib	M	32 ± 5
041	CaMNH	Johnston	36IN2	822	Fib	M	35 ± 5
042	CaMNH	Johnston	36IN2	823	Fib	F	42 ± 5
043	CaMNH	Johnston	36IN2	829	Fib	F	22 ± 5
044	CaMNH	Johnston	36IN2	832	Fib	M	47 ± 5
045	CaMNH	Montague	36SO4	4255(1)	Fib	M	27 ± 3
046	CaMNH	Montague	36SO4	4255(2)	Fib	F	33 ± 5
047	CaMNH	Kelso	36WH23	E601	Fib	F	25 ± 3
048	CaMNH	Felix	36WH85	4117	Fib	M	30 ± 5
049	CaMNH	Ashmore Farm	36WH675	2043	Fib	F	Adult
050	CaMNH	Finley	36WM18	E86	Fib	M	40
051	CaMNH	Household	36WM61	9613	Fib	M	37 ± 5
052	CaMNH	Household	36WM61	9611	Fib	F	50 ± 5
053	CaMNH	Household	36WM61	9617	Fib	M	35 ± 5
054	CaMNH	Household	36WM61	9615	Fib	F	53 ± 5
055	CaMNH	Household	36WM61	9624	Fib	F	30
056	CaMNH	Household	36WM61	9626	Fib	M	30 ± 5
057	CaMNH	King	36WM104	3822	Fib	M	Adult
058	CaMNH		46BR2	FC1855	Fib	M	37 ± 5
059	CaMNH	Globe Hill	46HK34-1	FC3040A	Fib	M	Adult
060	CaMNH	Household	36WM61	FC9635	Tib	M	37 ± 5

Table 74 (continued).

#	Source[1]	Site Name	Site #	Acc/Cat/Bur/Fea	Ele.[2]	Sex	Age
062	UKMA	Childers	46MS121	Fea 38, Bur 2	Tib	F?	Adult
063	UKMA	Childers	46MS121	Bankcut	Tib	M?	Adult
064	UKMA	Childers	46MS121	868/1283	Fib	--	Adult
065	UKMA	Childers	46MS121	1.4507	Fib	--	--
066	UKMA	Childers	46MS121	Fea 52, Bur 3	Fem	--	20 - 30
067	CMNH	Campbell Island	33BU2	Unit 1, Bur 1	Fem	M	25+
068	CMNH	Foster	--	--	Hum	M	--
069	CMNH	Sand Ridge	33HA17	Bur 1	Fib	--	--
070	CMNH	Watson	33BU297	Cat 1200/10, Bur 4	Fib	--	--
071	CMNH	Schomaker	33HA400	Bur 1	Hum	F	Adult
075	CMNH	Newtown Firehouse	33HA419	Bur B	Fib	F	35+
076	CMNH	Newtown Firehouse	33HA419	Bur H	Fib	M	40+
077	CMNH	Newtown Firehouse	33HA419	Bur A	Fib	M	35-40?
078	CMNH	Newtown Firehouse	33HA419	Bur D	Fib	M	45-50?
084	CMNH	Guard	12D29	Bur 6, FS 212	Fib	--	Y Adult
085	CMNH	Guard	12D29	Bur 9, FS 295	Fib	--	--
086	CMNH	Guard	12D29	Bur 7, FS 272	Fem	--	Y Adult
087	CMNH	Guard	12D29	Bur 5, FS 192	Fib	--	Y Adult
088	CMNH	Guard	12D29	Bur 10, FS 332	Fib	--	--
089	CMNH	Guard	12D29	Bur 21, Unit 18	Fib	F	--
090	CMNH	Guard	12D29	Bur 4, FS 153	Fib	--	Juv.
091	CMNH	Guard	12D29	Bur 3, FS 152	Fib	--	Adult
092	CMNH	Guard	12D29	Bur 12, Unit 17	Fib	F	Y Adult
093	CMNH	Guard	12D29	Bur 14, Unit 17	Fib	--	Adult
094	CMNH	Guard	12D29	Bur 20, Unit 18	Fib	M	Adult
095	CMNH	Guard	12D29	Bur 11, Unit 16	Fib	M	Y Adult
096	CMNH	Guard	12D29	Bur 15, Unit 17	Fib	--	Y Adult
097	CMNH	Guard	12D29	Bur 2, FS 123	Fib	F	--
098	CMNH	Guard	12D29	Bur 17, Unit 18	Fib	F	Adult
099	GBLA	CL Lewis	12SH2	Bur 27, Cat 187	Rad	--	Adult
100	GBLA	CL Lewis	12SH2	Bur 21, Cat 135	Fem	M	Adult
101	GBLA	CL Lewis	12SH2	Bur 26, Cat 214	Hum	--	Adult
102	GBLA	CL Lewis	12SH2	Bur 14, Cat 198	Fem	--	Adult

Table 74 (continued).

#	Source[1]	Site Name	Site #	Acc/Cat/Bur/Fea	Ele.[2]	Sex	Age
103	GBLA	CL Lewis	12SH2	Bur 5, Cat 135	Tib	--	Adult
104	GBLA	CL Lewis	12SH2	Bur 28, Cat 199	Ulna	F	Adult
105	GBLA	CL Lewis	12SH2	Bur 11, Cat 213	Fem	--	Adult
106	GBLA	CL Lewis	12SH2	Bur 8, Cat 121	Tib	--	Adult
107	GBLA	CL Lewis	12SH2	Bur 13, Cat 190	Hum	--	Adult
108	GBLA	CL Lewis	12SH2	Bur 18, Cat 170	Hum	M	Adult
109	GBLA	CL Lewis	12SH2	Bur 34, Cat 197	Fem	--	Adult
110	GBLA	CL Lewis	12SH2	Bur 29, Cat 208	Hum	--	Adult
111	GBLA	CL Lewis	12SH2	Bur 35, Cat 184	Fem	--	Adult
112	GBLA	CL Lewis	12SH2	Bur 12, Cat 189	Fem	--	Adult
113	GBLA	CL Lewis	12SH2	Bur 32, Cat 193	Fem	M	Adult
114	GBLA	CL Lewis	12SH2	Bur 22, Cat 202	Tib	--	Adult
134	UKMA	Cleek Mound	15BE8	Bur 45-10	Fem	--	Adult
145	UKMA	Cleek Mound	15BE8	Bur 45-2	Fem	--	Adult
147	CMNH	State Line	33HA58	Bur 1, Fea 500	Fib	--	Adult
148	CMNH	State Line	33HA58	Bur 5, Fea 506	Fib	F	20-24
149	CMNH	State Line	33HA58	Bur 6, Fea 507	Rad	M	24-29
150	CMNH	State Line	33HA58	Bur 4, Fea 505A	Fib	--	Adult
151	CMNH	State Line	33HA58	Bur 3, Fea 509B	Fib	--	Adult
152	CMNH	State Line	33HA58	Bur 2, Fea 505B	Fib	--	Adult
153	UKMA	Chilton	15HY1	Bur 49-11	Tib	M	Adult
154	UKMA	Chilton	15HY1	Bur 49-19	Rad	M	Adult
156	UKMA	Chilton	15HY1	Bur 49-14	Fem	--	Adult
158	UKMA	Chilton	15HY1	Bur 49-3	Fib	M	Adult
159	UKMA	Chilton	15HY1	Bur 49-20	Fib	F	Adult
160	UKMA	Chilton	15HY1	Bur 49-4	Fib	F	Adult
163	UKMA	Chilton	15HY1	Bur 49-29	Tib	F	Adult
164	UKMA	Chilton	15HY1	Bur 49-18	Fib	M	Adult
170	UKMA	Slone	15PI11	Bur 35	Fem	F	Adult
181	UKMA	Slone	15PI11	Bur 17	Fem	M	16-18
184	CMNH	Turpin (pattern)	33HA19	Cat 268	Fem	F?	25-54
186	CMNH	Turpin (pattern)	33HA19	Cat 289	Fib	M	30-35
190	CMNH	Turpin (pattern)	33HA19	Cat 220	Fib	F	15-19

Table 74 (continued).

#	Source[1]	Site Name	Site #	Acc/Cat/Bur/Fea	Ele.[2]	Sex	Age
198	CMNH	Turpin (pattern)	33HA19	Cat 236	Fib	M	30-39
200	CMNH	Turpin (pattern)	33HA19	Cat 216	Fib	M	20-24
202	CMNH	Turpin (pattern)	33HA19	Cat 231	Fib	M	35-54
206	CMNH	Turpin (pattern)	33HA19	Cat 213	Fib	M	35-39
209	CMNH	Turpin (LP mnd)	33HA19	Cat 103	Fib	M	25-29
211	CMNH	Turpin (LP mnd)	33HA19	Cat 134	Hum	M	45-54
214	CMNH	Turpin (LP mnd)	33HA19	Cat 108	Fib	M?	35-54
215	CMNH	Turpin (LP mnd)	33HA19	Cat 157	Fib	M	40+
219	CMNH	Turpin (LP mnd)	33HA19	Cat 155	Fib	F	25-29
220	CMNH	Turpin (LP mnd)	33HA19	Cat 156	Fib	M	35-54
224	CMNH	Turpin (LP mnd)	33HA19	Cat 159	Fib	F	30-35
227	CMNH	Turpin (LP mnd)	33HA19	Cat 141	Fib	M	25-34
228	CMNH	Turpin (LW mnd)	33HA19	Cat 86	Fem	M	30-40
229	CMNH	Turpin (LW mnd)	33HA19	Cat 80, Bur 37	Fib	I	Adult
230	CMNH	Turpin (LW mnd)	33HA19	Cat 83	Fib	F	45-54
231	CMNH	Turpin (LW mnd)	33HA19	Cat 82	Rad	M?	35-54
232	CMNH	Turpin (LW mnd)	33HA19	Cat 84	Fib	F	45-54
234	CMNH	Turpin (LW mnd)	33HA19	Cat 78, Bur 34	Fem	F	Adult
235	CMNH	Turpin (LW mnd)	33HA19	Cat 81, Bur 41	Tib	M	Adult
236	CMNH	Turpin (LW mnd)	33HA19	Cat 91	Fib	M	25-30
237	CMNH	Turpin (LW mnd)	33HA19	Cat 78, Bur 33	Fib	M	Adult
238	CMNH	Turpin (LW mnd)	33HA19	Cat 93	Fib	M	Adult
240	CMNH	Turpin (LW mnd)	33HA19	Cat 76, Bur 32	Fib	I	16-17
241	CMNH	Turpin (LW mnd)	33HA19	Cat 87	Tib	M	≈ 35
242	CMNH	Turpin (LW mnd)	33HA19	Cat 90	Ulna	F	35-54
243	CMNH	Turpin (LP mnd)	33HA19	Cat 151	Ulna	M	35-54
244	CMNH	Turpin (LW mnd)	33HA19	Cat 92	Fib	M	50+
245	CMNH	Turpin (LW mnd)	33HA19	Cat 89	Ulna	F	45+
246	CMNH	Turpin (LW mnd)	33HA19	Cat 88	Tib	F	≈ 40
247	Sciulli	Henderson Mnd 2		Ind 1	Rad	--	--
248	Sciulli	Henderson Mnd 2		Ind 2	Rad	--	--
249	Sciulli	Saddle	46MR95	Fea 47	Fib	M	35-39
250	Sciulli	Saddle	46MR95	Fea 9	Fib	M	40-44

Table 74 (continued).

#	Source[1]	Site Name	Site #	Acc/Cat/Bur/Fea	Ele.[2]	Sex	Age
251	Sciulli	Saddle	46MR95	Fea 92A	Fib	F	25-29
252	Sciulli	Saddle	46MR95	Fea 77	Fib	F	40-44
253	Sciulli	Saddle	46MR95	Fea 110	Fib	F	20-24
254	Sciulli	Saddle	46MR95	Fea 67B	Rad	M	35-39
255	Sciulli	Saddle	46MR95	Fea 63	Fib	M	40-44
256	Sciulli	Proctor	46NI84		Fib	F	45 ± 5
258	CMNH	Hawkins Ridge	33HA182	Acc 15290/1, FS 260	Hum	--	--
259	CMNH	Hawkins Ridge	33HA182	Acc 15289/1, FS 262	Hum	--	--
260	ClMNH	Hobson	33MS2	9122-5729	Fib	M	22-23
261	ClMNH	Wood-73	33WA92	9107-31A2090, Bur 1	Hum	M	35-40
262	ClMNH	Oglesby-Harris	33WA83	9163-33A2092 Bur 1	Fib	M	30-35
263	LC	Continental Constr.	33RO348	Fea 23, Locale 5, Bur 3	Hum	M	40-45
264	UC	Horseshoe Johnson	33BU204	Bur 1	Fib	F	50-60+
268	ClMNH	Bunnell Kame	33CN7	9055-10441, Bur 1	Fib	M	22-25
269	ClMNH	Bunnell Kame	33CN7	9081-17A2098-08, Bur 7	Fib	M	35-40
274	ClMNH	Riker	33TU02	9143-188A013, Bur 13A	Fib	--	--
275	ClMNH	Riker	33TU02	9140-188A012, Bur 22A	Fib	--	--
286	ClMNH	Killen	33AD36	9050-10055	Fem	--	--
288	ClMNH	Killen	33AD36	9039-9740, Bur 34a	LB	--	--
289	ClMNH	Killen	33AD36	9051-10158	Hum	--	--
291	ClMNH	Killen	33AD36	9030-9729, Bur 19a	LB	--	--
293	ClMNH	Killen	33AD36	9023-9722B, Bur 6a	Fem	--	--
296	ClMNH	Killen	33AD36	9017-9717, Bur 1a	Fib	--	--
297	ClMNH	Killen	33AD36	9029-9728, Bur 15a	Fib	--	--
298	ClMNH	Killen	33AD36	9026-9725, Bur 9a	Hum	--	--
299	ClMNH	Killen	33AD36	9035-9736, Bur 27a	Hum	--	--
300	ClMNH	Killen	33AD36	9020-9720, Bur 4a	Tib	--	--
301	ClMNH	Killen	33AD36	9027-9726, Bur 12a	Fem	--	--
302	ClMNH	Killen	33AD36	9032-9732, Bur 22a	Fem	--	--
303	ClMNH	Killen	33AD36	9033-9734, Bur 25a	Fem	--	--
304	ClMNH	Killen	33AD36	9037-9738, Bur 31a	Tib	--	--
307	CMNH	State Line	33HA58	Fea 215, Bur 46	Ulna	F	20-25
315	CMNH	State Line	33HA58	Fea 8, Bur 7	Tib	F?	23-28

Table 74 (continued).

#	Source[1]	Site Name	Site #	Acc/Cat/Bur/Fea	Ele.[2]	Sex	Age
327	CMNH	State Line	33HA58	Fea 585, Bur 59	Fib	M	Adult
339	OHS	Zencor	33FR8	Acc 88/490, Bur 1	Fib	M	Adult
340	OHS	Zencor	33FR8	Acc 88/491, Bur 2	Fib	--	--
341	OHS	Zencor	33FR8	Acc 88/492, Bur 3	Fib	--	--
342	OHS	Zencor	33FR8	Acc 88/493, Bur 4	Fib	--	--
343	OHS	Zencor	33FR8	Acc 88/696, Bur 4?	Fib	--	--
344	OHS	Zencor	33FR8	Acc 4084/5190A, Bur 6	Fib	--	--
345	OHS	Zencor	33FR8	Acc 4084/5158, Bur 3	Fib	--	--
346	OHS	Zencor	33FR8	Acc 4084/5156, Bur 1	Fib	--	--
347	OHS	Zencor	33FR8	Acc 4084/5201, Bur 11	Fib	--	--
348	OHS	Zencor	33FR8	Acc 4084/5172, Bur 4	Fib	--	--
350	OHS	Zencor	33FR8	Acc 4084/5195, Bur 8	Fib	--	--
351	OHS	Zencor	33FR8	Acc 4084/5189, Bur 5	Fib	--	--
353	OHS	Zencor	33FR8	Acc 4084/5203, Bur 12	Fib	--	--
354	OHS	Zencor	33FR8	Acc 4084/5196, Bur 9	Fib	--	--
356	OHS	Enos Holmes Mnd	33HI6	Acc 3754/359, Bur 1	Fib	--	--
357	OHS	Enos Holmes Mnd	33HI6	Acc 3754/361, Bur 3	Rad	--	--
358	OHS	Enos Holmes Mnd	33HI6	Acc 3754/376, Bur 5	Fib	--	--
359	OHS	Enos Holmes Mnd	33HI6	Acc 3754/381, Bur 7	Fib	--	--
360	OHS	Enos Holmes Mnd	33HI6	Acc 3754/402, Bur 8	Fib	--	--
361	OHS	Enos Holmes Mnd	33HI6	Acc 3754/1407, Bur 11	Fib	--	--
362	OHS	Enos Holmes Mnd	33HI6	Acc 3754/414, Bur 12	Fib	--	--
363	OHS	Enos Holmes Mnd	33HI6	Acc 3754/423, Bur 13	Fib	--	--
364	OHS	O.C. Voss Mnd	33FR52	Acc 3740/1, Bur 1	Fib	M	20-21
365	OHS	O.C. Voss Mnd	33FR52	Acc 3740/3, Bur 3	Fib	M	60-70
366	OHS	O.C. Voss Mnd	33FR52	Acc 3740/4, Bur 4	Fib	M	17-18
367	OHS	O.C. Voss Mnd	33FR52	Acc 3740/5, Bur 5	Fib	M	45-50
368	OHS	O.C. Voss Mnd	33FR52	Acc 3740/6, Bur 6	Fib	M	45-47
369	OHS	O.C. Voss Mnd	33FR52	Acc 3740/7, Bur 7	Fib	M	50-60
371	OHS	W. S. Cole	33DL11	Acc 3019/1	Fib	--	--
372	OHS	W. S. Cole	33DL11	Acc 3019/32	Rad	--	--
373	OHS	Ufferman	33DL12	Acc 3918/50	Fib	--	--
377	OHS	Campbell Island	33BU2	Bur A	Fib	--	--

Table 74 (continued).

#	Source[1]	Site Name	Site #	Acc/Cat/Bur/Fea	Ele.[2]	Sex	Age
379	OHS	Campbell Island	33BU2	Bur C	Fib	--	--
380	OHS	Feurt	33SC6	Acc 161, Bur C	Hum	--	--
382	OHS	Feurt	33SC6	Acc 297/99	Fib	--	--
383	OHS	Cramer	33RO33	Acc 3872/1	Hum	--	--
384	OHS	Cramer	33RO33	Acc 850/252	Ulna	--	--
385	OHS	Cramer	33RO33	Acc 850/253	Fib	--	--
386	OHS	Baldwin	33FA1?	Bur 2	Hum	--	--
387	OHS	Baldwin	33FA1?	Bur 4	Fib	--	--
388	OHS	Riker	33TU02	Acc 3787/1, Bur 1	Fib	--	--
389	OHS	Riker	33TU02	Acc 3787/2, Bur 2	Fib	--	--
400	OHS	Anderson	33WA4	Acc 2121/190, Bur A68	Fib	--	--
402	OHS	Anderson	33WA4	Acc 2121/204, Bur AB2	Fib	--	--
403	OHS	Anderson	33WA4	Acc 2121/221, Bur A99	Fib	--	--
404	OHS	Anderson	33WA4	Acc 2121/258, Bur OA3	Fib	--	--
408	OHS	Anderson	33WA4	Acc 2121/ (Box 170)	Fib	--	--
416	OHS	Anderson	33WA4	Acc 2121/161	Fib	--	--
417	OHS	Anderson	33WA4	Acc 2121/179	Fib	--	--
418	OHS	Anderson	33WA4	Acc 2121/195, Bur A73	Fib	--	--
419	Sciulli	Sony	36WM151	Bur 1	Fib	M	50 ± 10
420	Sciulli	Sony	36WM151	Bur 2	Fib	M	50 ± 10
421	Sciulli	Sony	36WM151	Bur 3	Fib	M	35 ± 5
422	Sciulli	Sony	36WM151	Bur 4	Fib	F	42 ± 5
423	Sciulli	Sony	36WM151	Bur 5	Fib	F	30 ± 5
424	Sciulli	Sony	36WM151	Bur 6	Fib	M	30 ± 5
425	Sciulli	Sony	36WM151	Bur 9	Fib	F?	18 ± 3
426	Sciulli	Sony	36WM151	Bur 11	Fib	M	45 ± 5
427	MU	Childers	46MS121	Fea 24	Hum	F?	15-18?

[1] CaMNH, Carnegie Museum of Natural History; ClMNH, Cleveland Museum of Natural History; CMNH, Cincinnati Museum of Natural History; GBLA, Glenn Black Laboratory of Archaeology, Indiana University; LC, Licking County Archaeology and Landmarks Society; MU, Marshall University; OHS, Ohio Historical Society; UC, University of Cincinnati; UKMA, University of Kentucky Museum of Anthropology

[2] Tib = Tibia; Fib = Fibula; Fem = Femur; Hum = Humerus; Rad = Radius

Table 75. "Collagen" yields (mg extract/mg bone).

Sample	% Yield Replicate 1	SE	%Yield[a] Replicate 2	SE[a]	% Yield Replicate 3	SE	Avg. Yield	SD
001	12.126	0.003	10.340	0.005	10.656	0.004	11.041	0.954
002	12.484	0.005	11.659	0.003	11.655	0.005	11.933	0.477
003	5.362	0.003	4.869	0.005	--	--	5.116	0.349
004	8.372	0.004	8.956	0.012	--	--	8.664	0.413
005	6.227	0.006	5.736	0.003	--	--	5.982	0.347
006	11.510	0.004	13.066	0.002	--	--	12.288	1.100
007	5.142	0.003	4.933	0.007	--	--	5.038	0.148
008	5.461	0.004	5.977	0.003	--	--	5.719	0.364
009	6.166	0.003	7.200	0.006	--	--	6.683	0.731
010	7.230	0.002	9.349	0.002	--	--	8.290	1.499
011	11.487	0.002	12.898	0.004	--	--	12.192	0.997
012	4.394	0.006	4.412	0.003	--	--	4.403	0.013
013	5.841	0.004	4.178	0.003	--	--	5.010	1.176
014	7.233	0.003	7.424	0.000	--	--	7.328	0.135
015	5.274	0.007	5.077	0.005	--	--	5.175	0.139
016	5.294	0.002	4.539	0.003	--	--	4.916	0.534
017	8.019	0.006	5.904	0.004	--	--	6.962	1.496
018	6.772	0.005	5.525	0.004	--	--	6.148	0.882
019	7.897	0.003	7.762	0.003	--	--	7.829	0.095
020	10.545	0.004	10.355	0.004	--	--	10.450	0.134
021	6.655	0.003	7.056	0.002	--	--	6.856	0.284
022	6.525	0.004	6.471	0.004	--	--	6.498	0.039
023	8.496	0.002	11.467	0.004	--	--	9.981	2.101
024	4.261	0.003	4.412	0.006	--	--	4.336	0.107
025	3.964	0.003	4.311	0.002	--	--	4.138	0.245
026	4.800	0.004	5.599	0.007	--	--	5.200	0.565
027	8.413	0.004	9.233	0.002	--	--	8.823	0.579
028	5.755	0.003	8.083	0.013	--	--	6.919	1.646
029	5.071	0.005	3.920	0.020	--	--	4.495	0.813
030	8.983	0.004	11.336	0.012	--	--	10.159	1.663
031	5.378	0.002	6.167	0.010	--	--	5.773	0.558
032	5.560	0.002	6.193	0.017	--	--	5.876	0.447

Table 75 (continued).

Sample	% Yield Replicate 1	SE	%Yield[a] Replicate 2	SE[a]	% Yield Replicate 3	SE	Avg. Yield	SD
033	5.251	0.007	5.370	0.005	--	--	5.310	0.084
034	8.310	0.004	9.133	0.004	--	--	8.721	0.582
035	7.775	0.004	5.687	0.006	--	--	6.731	1.476
036	5.603	0.003	4.913	0.004	--	--	5.258	0.488
037	6.942	0.004	6.461	0.004	--	--	6.702	0.340
038	4.104	0.006	3.902	0.002	--	--	4.003	0.142
039	14.393	0.009	15.286	0.002	--	--	14.840	0.632
040	28.385	0.013	27.180	0.006	--	--	27.782	0.852
041	16.571	0.011	16.412	0.004	--	--	16.491	0.112
042	27.349	0.009	28.490	0.006	--	--	27.919	0.807
043	7.800	0.008	7.481	0.005	--	--	7.640	0.225
044	6.946	0.011	7.692	0.007	--	--	7.319	0.527
045	6.958	0.014	6.074	0.008	8.024	0.004	7.019	0.977
046	8.344	0.012	7.710	0.006	--	--	8.027	0.449
047	4.258	0.008	3.466	0.010	--	--	3.862	0.560
048	8.145	0.006	6.605	0.007	--	--	7.375	1.089
049	6.567	0.005	5.657	0.005	--	--	6.112	0.644
050	6.897	0.004	7.626	0.003	--	--	7.261	0.516
051	9.145	0.005	8.537	0.007	--	--	8.841	0.430
052	5.200	0.006	5.079	0.006	--	--	5.139	0.086
053	5.198	0.004	5.809	0.006	--	--	5.504	0.432
054	5.257	0.007	7.012	0.008	--	--	6.135	1.241
055	2.169	0.006	3.275	0.002	--	--	2.722	0.783
056	7.599	0.005	6.045	0.004	--	--	6.822	1.099
057	6.414	0.006	7.173	0.002	--	--	6.794	0.536
058	5.019	0.004	5.117	0.013	--	--	5.068	0.070
059	23.333	0.005	23.636	0.004	--	--	23.484	0.214
060	7.249	0.004	6.701	0.001	--	--	6.975	0.388
062	1.487	0.006	1.189	0.005	--	--	1.338	0.211
063	4.589	0.003	4.741	0.012	--	--	4.665	0.107
064	4.296	0.003	4.809	0.003	--	--	4.552	0.363
065	4.748	0.005	4.844	0.003	--	--	4.796	0.068

Table 75 (continued).

Sample	% Yield Replicate 1	SE	%Yield[a] Replicate 2	SE[a]	% Yield Replicate 3	SE	Avg. Yield	SD
066	0.575	0.003	0.542	0.002	--	--	0.558	0.023
067	0.450	0.009	0.918	0.014	--	--	0.684	0.330
068	9.003	0.009	8.475	0.002	--	--	8.739	0.373
069	6.160	0.006	7.765	0.006	--	--	6.963	1.134
070	9.406	0.004	8.296	0.016	--	--	8.851	0.785
071	6.561	0.010	6.604	0.004	--	--	6.583	0.030
075	3.976	0.003	3.901	0.002	--	--	3.939	0.053
076	12.923	0.004	14.042	0.004	--	--	13.482	0.791
077	3.274	0.000	3.207	0.003	--	--	3.240	0.048
078	4.745	0.006	5.038	0.006	--	--	4.891	0.208
084	4.833	0.008	5.392	0.007	--	--	5.112	0.395
085	7.377	0.005	7.660	0.008	--	--	7.518	0.200
086	6.071	0.003	5.375	0.011	--	--	5.723	0.492
087	9.133	0.008	9.048	0.012	--	--	9.091	0.060
088	6.744	0.004	5.526	0.012	--	--	6.135	0.861
089	4.996	0.013	4.647	0.012	--	--	4.822	0.247
090	9.276	0.007	7.743	0.005	--	--	8.509	1.084
091	10.142	0.003	8.088	0.007	--	--	9.115	1.452
092	5.720	0.006	7.064	0.008	--	--	6.392	0.950
093	10.329	0.006	10.957	0.005	--	--	10.643	0.444
094	7.080	0.006	8.903	0.009	--	--	7.991	1.289
095	5.560	0.002	4.244	0.003	--	--	4.902	0.930
096	17.399	0.003	20.037	0.008	--	--	18.718	1.865
097	7.027	0.005	6.907	0.009	--	--	6.967	0.085
098	8.315	0.006	7.270	0.003	--	--	7.792	0.739
099	15.604	0.002	14.437	0.002	--	--	15.021	0.825
100	5.710	0.002	nd	nd	--	--	5.710	0.002
101	9.444	0.003	nd	nd	--	--	9.444	0.003
102	8.393	0.004	nd	nd	--	--	8.393	0.004
103	7.698	0.001	nd	nd	--	--	7.698	0.001
104	20.668	0.001	nd	nd	--	--	20.668	0.001
105	5.313	0.004	nd	nd	--	--	5.313	0.004

Table 75 (continued).

Sample	% Yield Replicate 1	SE	%Yield[a] Replicate 2	SE[a]	% Yield Replicate 3	SE	Avg. Yield	SD
106	5.029	0.003	6.735	0.004	6.601	0.011	6.122	0.949
107	11.669	0.004	nd	nd	--	--	11.669	0.004
108	4.364	0.006	nd	nd	--	--	4.364	0.006
109	6.395	0.003	nd	nd	--	--	6.395	0.003
110	9.027	0.004	nd	nd	--	--	9.027	0.004
111	5.980	0.003	6.174	0.002	--	--	6.077	0.138
112	4.576	0.003	nd	nd	--	--	4.576	0.003
113	5.559	0.004	6.623	0.003	5.087	0.011	5.757	0.787
114	6.871	0.005	7.545	0.004	--	--	7.208	0.477
134	2.156	0.005	1.794	0.007	--	--	1.975	0.256
145	4.716	0.007	4.230	0.011	4.639	0.007	4.528	0.261
147	5.542	0.008	5.999	0.004	--	--	5.770	0.323
148	9.816	0.008	9.590	0.008	--	--	9.703	0.159
149	21.595	0.009	22.010	0.013	--	--	21.803	0.293
150	5.570	0.004	4.645	0.005	--	--	5.108	0.654
151	6.884	0.005	7.034	0.007	--	--	6.959	0.106
152	5.688	0.003	5.597	0.002	--	--	5.642	0.064
153	3.583	0.006	5.912	0.002	--	--	4.747	1.647
154	20.504	0.004	18.638	0.005	--	--	19.571	1.319
156	7.636	0.003	12.715	0.004	12.550	0.010	10.967	2.886
158	15.219	0.002	12.507	0.006	--	--	13.863	1.918
159	7.639	0.004	9.696	0.003	--	--	8.668	1.455
160	4.682	0.004	5.508	0.003	--	--	5.095	0.584
163	5.553	0.007	3.524	0.004	4.366	0.007	4.481	1.020
164	9.876	0.005	10.032	0.003	--	--	9.954	0.110
170	7.672	0.007	5.406	0.006	--	--	6.539	1.602
181	4.196	0.007	3.398	0.007	3.857	0.005	3.817	0.401
184	5.656	0.004	5.925	0.009	--	--	5.791	0.190
186	12.380	0.011	11.718	0.005	--	--	12.049	0.468
190	4.344	0.012	4.434	0.004	--	--	4.389	0.064
198	5.099	0.010	5.774	0.011	--	--	5.437	0.477
200	7.907	0.011	8.705	0.012	--	--	8.306	0.565

Table 75 (continued).

Sample	% Yield Replicate 1	SE	%Yield[a] Replicate 2	SE[a]	% Yield Replicate 3	SE	Avg. Yield	SD
202	5.935	0.005	7.912	0.003	--	--	6.923	1.398
206	7.214	0.007	7.292	0.007	--	--	7.253	0.055
209	7.191	0.003	8.221	0.009	--	--	7.706	0.728
211	4.176	0.003	4.537	0.004	--	--	4.357	0.256
214	9.138	0.004	7.939	0.017	--	--	8.538	0.848
215	9.535	0.004	10.741	0.008	--	--	10.138	0.852
219	6.039	0.009	5.575	0.010	--	--	5.807	0.328
220	6.198	0.012	5.773	0.008	--	--	5.985	0.300
224	8.041	0.006	9.176	0.012	8.024	0.005	8.414	0.660
227	10.586	0.003	9.797	0.009	--	--	10.191	0.558
228	4.266	0.002	7.177	0.002	--	--	5.721	2.058
229	4.662	0.003	4.486	0.004	5.519	0.010	4.889	0.552
230	4.502	0.005	5.013	0.004	--	--	4.758	0.362
231	4.662	0.004	nd	nd	--	--	4.662	0.004
232	4.216	0.003	6.041	0.004	--	--	5.128	1.291
234	3.747	0.007	4.323	0.002	--	--	4.035	0.408
235	4.781	0.004	4.031	0.005	5.402	0.006	4.738	0.687
236	4.524	0.003	4.676	0.003	4.729	0.006	4.643	0.107
237	4.609	0.004	5.139	0.003	--	--	4.874	0.375
238	5.881	0.006	9.110	0.004	--	--	7.496	2.284
240	4.292	0.003	5.131	0.003	--	--	4.711	0.593
241	6.784	0.003	8.540	0.001	--	--	7.662	1.242
242	4.874	0.003	5.856	0.002	--	--	5.365	0.695
243	4.863	0.004	3.218	0.003	--	--	4.040	1.163
244	6.548	0.003	7.325	0.002	--	--	6.937	0.550
245	3.767	0.003	5.795	0.004	--	--	4.781	1.434
246	7.411	0.005	9.266	0.003	--	--	8.338	1.311
247	3.832	0.006	5.718	0.000	--	--	4.775	1.334
248	6.442	0.003	6.890	0.003	--	--	6.666	0.317
249	6.676	0.006	5.507	0.002	--	--	6.091	0.826
250	4.108	0.006	3.789	0.009	--	--	3.948	0.226
251	6.791	0.002	5.740	0.003	--	--	6.266	0.743

Table 75 (continued).

Sample	% Yield Replicate 1	SE	%Yield[a] Replicate 2	SE[a]	% Yield Replicate 3	SE	Avg. Yield	SD
252	6.729	0.002	6.677	0.019	--	--	6.703	0.037
253	6.794	0.003	6.236	0.012	--	--	6.515	0.394
254	6.661	0.006	5.831	0.006	--	--	6.246	0.587
255	4.548	0.010	4.239	0.007	--	--	4.394	0.218
256	29.872	0.008	26.775	0.012	--	--	28.323	2.190
258	4.461	0.003	4.509	0.002	--	--	4.485	0.034
259	5.769	0.005	5.702	0.004	--	--	5.736	0.047
260	6.079	0.009	5.657	0.009	--	--	5.868	0.299
261	7.275	0.003	7.203	0.012	--	--	7.239	0.051
262	6.458	0.011	6.000	0.013	--	--	6.229	0.324
263	6.787	0.005	8.756	0.004	--	--	7.771	1.393
264	6.644	0.003	7.855	0.005	--	--	7.250	0.856
268	7.035	0.011	7.457	0.005	--	--	7.246	0.298
269	6.759	0.008	4.926	0.007	--	--	5.842	1.296
274	12.081	0.004	10.484	0.008	--	--	11.283	1.130
275	5.113	0.012	5.106	0.004	--	--	5.110	0.005
286	4.152	0.010	5.235	0.012	--	--	4.693	0.766
288	1.904	0.011	2.547	0.015	2.622	0.007	2.357	0.395
289	2.265	0.012	1.884	0.008	--	--	2.074	0.270
291	3.098	0.012	2.735	0.006	4.886	0.015	3.573	1.151
293	3.151	0.009	3.444	0.004	2.807	0.004	3.134	0.319
296	3.155	0.013	2.883	0.004	--	--	3.019	0.193
297	7.941	0.005	8.577	0.010	--	--	8.259	0.450
298	1.569	0.011	3.362	0.007	5.259	0.007	3.397	1.845
299	4.839	0.007	5.036	0.004	--	--	4.937	0.139
300	7.383	0.012	7.542	0.011	--	--	7.463	0.112
301	4.236	0.018	3.414	0.008	--	--	3.825	0.581
302	1.946	0.010	2.171	0.006	1.610	0.006	1.909	0.282
303	1.411	0.009	1.606	0.011	1.521	0.002	1.513	0.098
304	5.609	0.008	7.062	0.005	--	--	6.335	1.028
307	3.490	0.004	5.648	0.004	6.203	0.004	5.114	1.434
315	4.004	0.003	6.405	0.013	--	--	5.204	1.698

Table 75 (continued).

Sample	% Yield Replicate 1	SE	%Yield[a] Replicate 2	SE[a]	% Yield Replicate 3	SE	Avg. Yield	SD
327	5.337	0.006	6.566	0.004	--	--	5.951	0.869
339	3.270	0.000	5.526	0.011	--	--	4.398	1.595
340	5.338	0.002	7.351	0.006	--	--	6.345	1.424
341	7.002	0.007	6.436	0.005	--	--	6.719	0.400
342	6.395	0.006	9.913	0.002	--	--	8.154	2.488
343	4.921	0.003	5.119	0.010	--	--	5.020	0.140
344	7.329	0.008	8.531	0.007	--	--	7.930	0.850
345	4.320	0.007	4.580	0.006	--	--	4.450	0.184
346	3.987	0.010	4.251	0.007	--	--	4.119	0.187
347	6.189	0.006	5.057	0.012	--	--	5.623	0.801
348	3.761	0.002	4.392	0.003	--	--	4.076	0.446
350	4.301	0.013	5.551	0.008	--	--	4.926	0.884
351	6.677	0.012	6.125	0.005	--	--	6.401	0.390
353	3.675	0.004	4.054	0.000	--	--	3.864	0.268
354	6.944	0.006	6.638	0.012	--	--	6.791	0.217
356	3.827	0.003	7.198	0.010	--	--	5.512	2.384
357	3.520	0.006	6.600	0.016	--	--	5.060	2.178
358	7.614	0.011	6.997	0.009	--	--	7.305	0.437
359	8.333	0.009	7.847	0.006	--	--	8.090	0.344
360	10.059	0.003	15.390	0.002	--	--	12.724	3.770
361	12.671	0.008	16.816	0.009	--	--	14.743	2.931
362	7.436	0.013	7.068	0.007	--	--	7.252	0.260
363	1.818	0.005	6.380	0.003	7.108	0.005	5.102	2.867
364	14.514	0.008	14.487	0.006	--	--	14.501	0.019
365	8.828	0.007	7.314	0.006	--	--	8.071	1.070
366	11.063	0.009	12.445	0.010	--	--	11.754	0.977
367	11.239	0.008	11.350	0.002	--	--	11.295	0.078
368	8.478	0.012	9.045	0.007	--	--	8.761	0.401
369	8.688	0.011	8.373	0.007	--	--	8.531	0.222
371	3.735	0.002	6.814	0.002	7.314	0.004	5.954	1.938
372	7.699	0.005	9.662	0.000	--	--	8.681	1.388
373	3.979	0.007	7.484	0.009	--	--	5.732	2.478

Table 75 (continued).

Sample	% Yield Replicate 1	SE	%Yield[a] Replicate 2	SE[a]	% Yield Replicate 3	SE	Avg. Yield	SD
377	6.090	0.011	5.807	0.018	--	--	5.949	0.200
379	9.529	0.009	7.278	0.008	--	--	8.403	1.591
380	5.932	0.004	6.136	0.009	4.947	0.004	5.672	0.636
382	3.708	0.013	3.402	0.015	--	--	3.555	0.216
383	7.514	0.010	8.065	0.007	--	--	7.789	0.389
384	7.597	0.008	6.165	0.004	--	--	6.881	1.013
385	19.533	0.009	21.195	0.004	--	--	20.364	1.175
386	5.355	0.015	6.393	0.019	7.512	0.005	6.420	1.079
387	7.020	0.005	7.554	0.004	--	--	7.287	0.377
388	11.003	0.009	10.064	0.008	--	--	10.533	0.664
389	7.828	0.009	6.892	0.010	7.469	0.003	7.396	0.472
400	8.118	0.005	7.547	0.013	--	--	7.832	0.404
402	8.536	0.007	9.545	0.006	--	--	9.040	0.713
403	7.363	0.011	7.637	0.006	--	--	7.500	0.194
404	10.548	0.019	10.950	0.010	--	--	10.749	0.284
408	7.086	0.004	7.413	0.004	--	--	7.250	0.231
416	9.201	0.010	10.650	0.007	--	--	9.925	1.024
417	7.379	0.007	8.711	0.013	--	--	8.045	0.942
418	13.239	0.010	15.328	0.006	--	--	14.283	1.477
419	6.888	0.002	8.077	0.003	--	--	7.482	0.841
420	5.875	0.005	6.215	0.003	--	--	6.045	0.240
421	6.504	0.005	6.685	0.003	--	--	6.594	0.128
422	5.759	0.000	6.859	0.002	--	--	6.309	0.778
423	6.440	0.002	4.872	0.003	--	--	5.656	1.109
424	4.297	0.001	4.191	0.003	--	--	4.244	0.076
425	5.967	0.003	6.868	0.000	--	--	6.418	0.637
426	9.468	0.003	9.686	0.002	--	--	9.577	0.154

[a] nd, no data; the electronic balance malfunctioned and these samples could not be weighed according to the protocol

Table 76. Nitrogen and carbon concentrations (wt. %) and elemental C/N ratios for 95 "collagen" extracts. Repeat measurements are shown for five extracts.

Sample	%N	%C	C/N[a]	%N	%C	C/N[a]
003	14.651	41.621	3.313	--	--	--
009	14.017	39.736	3.306	--	--	--
021	13.625	39.976	3.422	--	--	--
027	14.243	41.214	3.375	--	--	--
028	13.141	37.421	3.321	--	--	--
030	14.737	42.027	3.326	--	--	--
033	13.706	38.963	3.315	--	--	--
036	13.567	39.916	3.431	--	--	--
042	14.806	41.655	3.281	--	--	--
044	13.368	38.312	3.342	--	--	--
047	13.197	38.254	3.380	--	--	--
051	13.340	37.756	3.301	--	--	--
054	14.624	41.930	3.344	--	--	--
062	12.527	37.508	3.492	--	--	--
063	14.497	41.454	3.335	--	--	--
066	5.095	20.154	4.613	--	--	--
067	8.002	27.112	3.951	--	--	--
071	13.827	39.010	3.290	--	--	--
076	14.515	41.203	3.310	--	--	--
078	14.238	40.650	3.329	--	--	--
085	12.974	36.867	3.314	--	--	--
088	13.400	37.863	3.295	--	--	--
090	13.011	36.953	3.312	--	--	--
094	13.351	37.581	3.283	--	--	--
097	13.214	37.481	3.308	13.252	37.665	3.314
099	14.906	41.955	3.282	--	--	--
103	13.624	38.191	3.269	14.315	40.232	3.277
104	15.169	42.891	3.297	--	--	--
107	13.400	38.230	3.327	--	--	--
111	15.153	43.067	3.314	--	--	--
134	11.244	34.630	3.592	--	--	--

Table 76 (continued).

Sample	%N	%C	C/N[a]	%N	%C	C/N[a]
149	13.766	38.639	3.273	--	--	--
153	13.359	41.495	3.622	--	--	--
154	14.771	42.615	3.365	--	--	--
158	13.856	41.361	3.481	--	--	--
160	13.237	38.969	3.433	--	--	--
163	11.033	38.189	4.037	10.787	37.904	4.098
181	10.714	37.258	4.055	--	--	--
186	13.998	39.293	3.274	--	--	--
209	13.911	39.637	3.323	--	--	--
211	13.237	37.623	3.314	--	--	--
214	12.712	35.942	3.297	--	--	--
220	13.080	36.998	3.299	--	--	--
230	13.745	39.258	3.331	--	--	--
231	13.362	38.131	3.328	--	--	--
232	13.621	38.761	3.319	--	--	--
238	14.505	41.944	3.372	--	--	--
240	14.705	41.659	3.304	--	--	--
242	13.398	38.207	3.325	--	--	--
243	14.372	41.246	3.347	--	--	--
244	14.440	40.617	3.280	--	--	--
247	14.860	42.766	3.356	--	--	--
248	13.637	38.447	3.288	--	--	--
251	15.230	43.887	3.360	--	--	--
253	14.706	41.639	3.302	--	--	--
259	13.945	40.153	3.358	--	--	--
260	12.703	36.395	3.341	--	--	--
261	13.455	38.651	3.350	--	--	--
262	13.200	38.415	3.394	--	--	--
263	14.744	41.776	3.304	--	--	--
269	12.709	36.603	3.358	--	--	--
286	12.666	36.499	3.360	--	--	--
288	10.467	33.901	3.777	--	--	--
289	10.452	32.899	3.671	--	--	--

Table 76 (continued).

Sample	%N	%C	C/N[a]	%N	%C	C/N[a]
291	10.505	31.483	3.495	--	--	--
299	13.412	38.638	3.359	--	--	--
301	12.621	36.805	3.401	12.717	36.959	3.389
302	7.212	27.480	**4.443**	--	--	--
303	9.041	30.077	**3.879**	--	--	--
315	13.626	38.989	3.337	--	--	--
327	13.155	37.661	3.339	--	--	--
339	16.324	45.763	3.269	--	--	--
344	13.665	38.834	3.314	--	--	--
348	13.786	39.674	3.356	--	--	--
351	14.006	39.730	3.308	--	--	--
357	13.080	38.364	3.420	--	--	--
358	13.618	39.227	3.359	--	--	--
360	13.797	39.808	3.365	--	--	--
365	13.706	39.336	3.347	--	--	--
367	14.126	39.731	3.280	--	--	--
368	13.717	39.019	3.317	--	--	--
372	13.863	39.232	3.300	--	--	--
377	13.581	39.668	3.406	--	--	--
382	13.008	37.532	3.365	--	--	--
384	13.590	38.786	3.328	13.615	38.761	3.320
387	12.763	36.788	3.361	--	--	--
388	13.637	38.725	3.312	--	--	--
400	13.591	39.268	3.369	--	--	--
408	13.200	37.617	3.323	--	--	--
417	13.491	38.240	3.306	--	--	--
421	14.481	40.409	3.254	--	--	--
422	14.456	40.629	3.278	--	--	--
424	14.527	41.489	3.331	--	--	--
426	14.306	40.907	3.335	--	--	--

[a] Samples with C/N ratios outside the range of modern collagen are in boldface.

Table 77. Manometrically-determined %C for "collagen" replicates.

Sample	%C #1	%C #2	%C #3	Average
001	41.03	40.67	--	40.85
002	39.29	40.60	42.74	40.88
003	41.59	42.23	--	41.91
004	40.83	nd	--	40.83
005	35.26	40.62	--	37.94
006	42.46	39.89	--	41.18
007	43.76	43.63	44.09	43.82
008	39.96	41.65	--	40.81
009	39.13	42.23	--	40.68
010	42.00	42.61	--	42.31
011	41.57	38.82	--	40.20
012	39.41	40.68	--	40.05
013	39.77	41.79	--	40.78
014	40.54	40.42	--	40.48
015	36.45	42.16	--	39.31
016	40.86	42.69	--	41.78
017	39.16	40.26	--	39.71
018	42.38	44.10	--	43.24
019	40.94	41.24	--	41.09
020	41.08	42.53	--	41.81
021	40.63	42.56	--	41.60
022	39.20	42.31	--	40.76
023	43.00	40.57	--	41.79
024	42.77	41.56	--	42.17
025	41.61	38.95	--	40.28
026	42.50	nd	--	42.50
027	44.03	nd	--	44.03
028	42.14	nd	--	42.14
029	40.83	nd	--	40.83
030	41.70	nd	--	41.70
031	41.98	nd	--	41.98
032	42.24	nd	--	42.24
033	38.51	42.39	--	40.45
034	37.95	40.12	--	39.04
035	43.23	43.20	--	43.22
036	40.59	42.45	--	41.52
037	38.76	nd	--	38.76
038	nd	40.88	--	40.88
039	41.65	42.55	--	42.10
040	39.07	nd	--	39.07

Table 77 (continued).

Sample	%C #1	%C #2	%C #3	Average
041	39.07	39.13	--	39.10
042	44.68	43.20	--	43.94
043	38.03	nd	--	38.03
044	39.28	41.29	--	40.29
045	40.21	41.98	--	41.09
046	nd	41.22	--	41.22
047	nd	41.09	--	41.09
048	nd	43.13	--	43.13
049	nd	44.04	--	44.04
050	41.74	nd	--	41.74
051	nd	40.37	--	40.37
052	39.37	42.30	--	40.84
053	40.20	40.10	--	40.15
054	46.87	nd	--	46.87
055	41.01	39.31	--	40.16
056	nd	45.17	--	45.17
057	41.93	41.40	--	41.67
058	41.28	41.50	--	41.39
059	45.38	42.45	--	43.92
060	41.92	nd	--	41.92
062	35.96	42.11	--	39.04
063	43.64	43.46	--	43.55
064	41.87	32.19	--	37.03
065	47.18	41.08	--	44.13
066	20.65	33.12	--	26.89
067	28.55	27.07	--	27.81
068	38.19	43.15	--	40.67
069	39.09	41.82	--	40.46
070	41.40	38.83	--	40.12
071	39.40	43.12	--	41.26
075	39.91	38.79	--	39.35
076	40.90	44.73	--	42.82
077	40.71	44.81	--	42.76
078	40.78	39.04	--	39.91
084	43.71	42.96	--	43.34
085	39.34	36.53	--	37.94
086	38.44	43.95	--	41.20
087	42.05	41.52	--	41.79
089	39.08	43.3	--	41.19
091	37.40	40.52	--	38.96

Table 77 (continued).

Sample	%C #1	%C #2	%C #3	Average
092	nd	43.76	--	43.76
093	38.61	39.01	--	38.81
094	39.26	38.71	--	38.99
095	nd	43.01	--	43.01
096	42.48	nd	--	42.48
097	38.53	37.83	--	38.18
098	38.83	40.69	--	39.76
099	43.15	39.05	--	41.10
100	43.52	nd	--	43.52
101	41.31	40.41	--	40.86
102	36.39	43.18	--	39.79
103	39.79	35.71	--	37.75
104	42.05	41.89	--	41.97
105	43.37	36.34	--	39.86
106	42.51	40.18	41.30	41.33
107	39.77	41.09	--	40.43
108	40.13	39.82	--	39.98
109	40.53	42.51	--	41.52
110	41.90	39.03	--	40.47
111	41.95	40.87	--	41.41
112	39.35	41.29	--	40.32
113	43.12	41.94	40.38	41.81
114	39.91	nd	--	39.91
145	40.95	42.05	42.55	41.85
147	42.02	41.60	--	41.81
148	nd	40.38	--	40.38
149	40.62	nd	--	40.62
150	34.79	43.72	--	39.26
151	42.01	40.22	--	41.12
152	43.29	45.71	--	44.50
153	40.07	44.85	--	42.46
154	41.47	41.85	--	41.66
156	41.48	43.17	40.16	41.60
158	43.80	41.90	--	42.85
159	46.41	45.00	--	45.71
160	38.32	40.22	--	39.27
163	39.55	38.96	--	39.25
164	44.82	41.47	--	43.15
170	37.16	42.79	--	39.98
181	nd	nd	39.85	39.85

Table 77 (continued).

Sample	%C #1	%C #2	%C #3	Average
184	41.43	nd	--	41.43
186	41.09	40.42	--	40.76
190	40.10	40.28	--	40.19
198	43.37	42.33	--	42.85
200	39.84	40.50	--	40.17
202	42.48	nd	--	42.48
206	41.71	nd	--	41.71
209	41.12	40.85	--	40.99
211	43.31	42.00	--	42.66
214	39.03	nd	--	39.03
215	40.15	nd	--	40.15
219	39.56	40.10	--	39.83
220	39.13	nd	--	39.13
224	41.85	41.14	--	41.50
227	41.80	nd	--	41.80
228	44.22	41.52	--	42.87
229	41.42	40.48	39.94	40.61
230	40.06	27.7	--	33.88
231	41.06	40.18	--	40.62
232	42.00	40.69	--	41.35
234	41.20	44.19	--	42.70
235	nd	42.77	40.52	41.65
236	42.58	42.95	37.84	41.12
237	45.07	47.77	--	46.42
238	42.82	42.51	--	42.67
240	41.21	40.96	--	41.09
241	41.76	42.26	--	42.01
242	39.78	41.29	--	40.54
243	41.43	nd	--	41.43
244	41.81	43.39	--	42.60
245	40.62	42.95	--	41.79
246	42.08	40.94	--	41.51
247	39.66	43.28	--	41.47
248	40.97	43.50	--	42.24
249	nd	45.10	--	45.10
250	42.79	42.30	--	42.55
251	nd	43.08	--	43.08
252	37.37	40.47	--	38.92
253	43.41	44.18	--	43.80
254	43.13	42.91	--	43.02

Table 77 (continued).

Sample	%C #1	%C #2	%C #3	Average
255	41.69	43.45	--	42.57
256	45.30	45.34	--	45.32
258	43.33	41.73	--	42.53
259	47.44	42.82	--	45.13
261	39.83	39.79	--	39.81
262	nd	41.17	--	41.17
263	44.79	41.20	--	43.00
264	43.30	nd	--	43.30
268	40.94	42.74	--	41.84
269	nd	40.11	--	40.11
274	nd	43.11	--	43.11
275	41.55	40.01	--	40.78
286	38.09	nd	--	38.09
288	37.02	36.15	39.31	37.49
291	35.42	nd	39.79	37.61
293	nd	39.10	42.42	40.76
296	35.48	39.15	--	37.32
297	nd	39.71	--	39.71
298	nd	38.45	39.95	39.20
299	40.98	40.28	--	40.63
300	42.11	nd	--	42.11
301	39.24	41.86	--	40.55
302	36.40	nd	36.22	36.31
303	nd	nd	28.76	28.76
304	42.68	42.52	--	42.60
307	40.79	39.69	43.20	41.22
315	nd	42.46	--	42.46
327	nd	41.16	--	41.16
339	35.51	39.89	--	37.70
340	38.27	41.51	--	39.89
341	42.36	40.10	--	41.23
342	43.69	39.95	--	41.82
343	38.49	nd	--	38.49
344	42.95	39.10	--	41.03
345	39.76	nd	--	39.76
346	41.24	39.95	--	40.60
347	41.93	nd	--	41.93
348	34.57	38.67	--	36.62
350	38.79	39.24	--	39.02
351	40.71	42.11	--	41.41

Table 77 (continued).

Sample	%C #1	%C #2	%C #3	Average
353	41.96	40.91	--	41.43
354	41.21	41.64	--	41.43
356	39.02	nd	--	39.02
357	41.98	nd	--	41.98
358	40.83	42.48	--	41.66
359	43.37	42.70	--	43.04
360	39.24	nd	--	39.24
361	42.89	36.04	--	39.47
362	42.85	43.28	--	43.07
363	35.11	39.71	42.16	38.99
364	40.67	41.03	--	40.85
365	39.84	42.65	--	41.25
366	42.84	38.57	--	40.71
367	40.88	38.48	--	39.68
368	39.22	40.39	--	39.81
369	38.37	nd	--	38.37
371	42.40	40.66	45.51	42.86
372	41.40	42.59	--	41.99
373	40.52	nd	--	40.52
377	nd	40.23	--	40.23
379	40.26	40.78	--	40.52
380	40.18	42.79	43.33	42.10
382	38.25	41.31	--	39.78
383	39.33	nd	--	39.33
384	nd	40.71	--	40.71
385	nd	45.05	--	45.05
386	41.14	41.16	39.65	40.65
387	42.81	nd	--	42.81
388	nd	40.65	--	40.65
389	40.54	40.31	40.24	40.36
400	40.35	38.99	--	39.67
402	44.74	nd	--	44.74
403	41.25	nd	--	41.25
404	38.94	nd	--	38.94
408	40.90	38.41	--	39.66
416	42.76	40.18	--	41.47
417	44.07	40.55	--	42.31
418	45.61	41.76	--	43.69
419	38.16	43.97	--	41.07
420	41.14	42.33	--	41.74

Table 77 (continued).

Sample	%C #1	%C #2	%C #3	Average
421	39.78	41.00	--	40.39
422	46.03	41.54	--	43.79
423	44.42	38.99	--	41.71
424	43.50	42.39	--	42.95
425	42.06	42.45	--	42.25
426	43.71	41.09	--	42.40

nd = %C not available due to incomplete transfer of material during weighing, failure to record necessary data, or changes in line volume.

Table 78. Amino acid compositions of modern human bone collagen (Woodhead-Galloway 1980) and archaeological "collagen" samples.

	Modern	028	062	063	076	078	085	101	104
ALA	114	114	113	117	113	117	113	115	115
GLY	319	314	343	320	315	323	333	317	324
VAL	24	27	26	24	26	23	24	26	24
LEU	25	26	24	23	25	24	23	24	24
ILE	13	11	11	10	10	10	10	10	10
PRO	123	131	105	128	136	129	126	135	127
PHE	14	13	13	15	13	15	14	13	13
TYR	5	3	6	3	3	2	3	2	1
SER	36	34	34	33	33	34	33	32	33
THR	18	18	20	18	18	18	18	18	17
MET	5	4	4	5	3	4	4	3	5
ARG	47	54	46	53	56	51	52	55	55
HIS	6	5	3	4	5	4	5	4	4
LYS	28	27	26	27	27	25	26	27	29
ASP	47	48	56	46	46	47	47	47	45
GLU	72	75	70	75	73	74	73	74	77
HYP	100	93	96	94	94	95	92	94	94
HYL	4	4	5	4	4	4	4	4	4
Σ	1000	1001	1001	999	1000	999	1000	1000	1001

Table 78 (continued).

	Modern	107	111	112	134	153	154	158	163
ALA	114	115	115	115	122	118	116	114	121
GLY	319	316	325	317	315	318	336	316	326
VAL	24	26	24	27	27	26	25	26	25
LEU	25	24	23	25	24	23	24	25	22
ILE	13	10	10	10	11	10	10	10	10
PRO	123	135	130	135	125	132	125	133	130
PHE	14	13	13	13	17	12	14	13	14
TYR	5	2	2	2	2	3	2	3	2
SER	36	33	33	32	34	33	33	33	33
THR	18	18	17	18	20	18	17	18	17
MET	5	4	5	3	3	4	5	4	4
ARG	47	54	52	54	46	53	52	55	46
HIS	6	4	4	4	3	3	4	4	2
LYS	28	27	25	25	24	25	24	26	23
ASP	47	46	45	47	53	48	45	46	50
GLU	72	73	77	74	76	74	73	73	79
HYP	100	97	95	94	93	95	93	96	94
HYL	4	4	3	4	3	3	3	3	3
Σ	1000	1001	998	999	998	998	1001	998	1001

Table 78 (continued).

	Modern	164	228	230	231	238	240	242	247
ALA	114	118	117	113	114	114	113	114	118
GLY	319	329	308	322	314	322	315	315	327
VAL	24	27	29	24	26	24	26	26	24
LEU	25	26	29	24	24	25	25	25	23
ILE	13	11	10	10	10	11	10	10	10
PRO	123	100	129	130	128	129	135	134	127
PHE	14	13	13	13	12	15	13	13	13
TYR	5	3	3	3	4	3	3	3	1
SER	36	34	32	34	33	34	33	33	32
THR	18	18	17	18	18	18	18	18	17
MET	5	4	4	4	2	4	4	3	2
ARG	47	56	54	53	53	53	55	54	52
HIS	6	4	5	5	5	5	5	4	3
LYS	28	26	26	26	26	26	28	27	27
ASP	47	49	48	47	52	46	46	47	48
GLU	72	76	78	76	79	74	73	73	78
HYP	100	100	93	94	96	94	94	97	95
HYL	4	4	4	4	4	4	4	3	4
Σ	1000	998	999	1000	1000	1001	1000	999	1001

Table 78 (continued).

	Modern	339	348	357	360	367	372	373
ALA	114	115	114	113	114	115	113	115
GLY	319	315	316	313	316	323	324	320
VAL	24	26	26	27	27	25	24	27
LEU	25	24	24	26	26	25	23	24
ILE	13	10	10	10	10	11	10	10
PRO	123	131	134	134	133	128	130	132
PHE	14	13	13	13	13	14	13	12
TYR	5	3	3	3	2	3	2	3
SER	36	33	32	34	34	34	34	32
THR	18	18	18	19	18	18	18	17
MET	5	3	3	4	4	3	4	4
ARG	47	55	56	54	54	53	53	54
HIS	6	4	5	5	5	4	4	4
LYS	28	27	27	25	27	26	27	25
ASP	47	47	45	49	46	46	45	47
GLU	72	76	74	74	74	75	76	75
HYP	100	96	97	92	94	94	96	94
HYL	4	4	4	3	4	4	4	4
Σ	1000	1000	1001	998	1001	1001	1000	999

Table 79. Stable carbon isotope measurements of "collagen" replicates and associated standard errors. Data are in units ‰ PDB.

	Replicate #1		Replicate #2		Replicate #3			
Sample	$\delta^{13}C$	SE	$\delta^{13}C$	SE	$\delta^{13}C$	SE	Avg. $\delta^{13}C$	SE
001	-8.41	0.00	-8.42	0.08	--	--	-8.42	0.06
002	-9.52	0.03	-8.90	0.07	-8.91	0.02	-8.90	0.04
003	-8.84	0.05	-8.61	0.00	--	--	-8.73	0.17
004	-8.61	0.01	-8.78	0.01	--	--	-8.70	0.12
005	-11.76	0.02	-11.54	0.00	--	--	-11.65	0.16
006	-7.93	0.02	-7.99	0.00	--	--	-7.96	0.04
007	-9.19	0.08	-10.23	0.01	-10.24	0.02	-10.23	0.02
008	-8.42	0.01	-8.51	0.04	--	--	-8.47	0.07
009	-9.03	0.00	-9.06	0.03	--	--	-9.05	0.03
010	-11.62	0.01	-11.72	0.01	--	--	-11.67	0.07
011	-11.59	0.04	-11.39	0.01	--	--	-11.49	0.14
012	-12.19	0.00	-12.38	0.01	--	--	-12.29	0.13
013	-10.57	0.02	-10.53	0.00	--	--	-10.55	0.03
014	-9.32	0.01	-9.25	0.02	--	--	-9.29	0.05
015	-9.99	0.02	-10.01	0.02	--	--	-10.00	0.02
016	-8.79	0.01	-8.88	0.06	--	--	-8.84	0.08
017	-9.30	0.00	-9.13	0.04	--	--	-9.22	0.12
018	-15.88	0.00	-15.98	0.02	--	--	-15.93	0.07
019	-9.29	0.01	-9.39	0.00	--	--	-9.34	0.07
020	-7.96	0.01	-7.97	0.02	--	--	-7.97	0.02
021	-11.93	0.00	-12.14	0.09	--	--	-12.04	0.16
022	-16.74	0.03	-16.82	0.02	--	--	-16.78	0.06
023	-9.53	0.02	-9.5	0.02	--	--	-9.52	0.03
024	-11.48	0.06	-11.33	0.01	--	--	-11.41	0.11
025	-10.14	0.01	-10.16	0.02	--	--	-10.15	0.02
026	-11.09	0.02	-11.26	0.02	--	--	-11.18	0.12
027	-13.29	0.12	-13.4	0.08	--	--	-13.34	0.13
028	-8.50	0.01	-8.55	0.01	--	--	-8.53	0.04
029	-11.19	0.04	-11.33	0.01	--	--	-11.26	0.10
030	-8.21	0.01	-8.18	0.02	--	--	-8.20	0.03
031	-7.46	0.00	-7.44	0.06	--	--	-7.45	0.04

Table 79 (continued).

	Replicate #1		Replicate #2		Replicate #3			
Sample	$\delta^{13}C$	SE	$\delta^{13}C$	SE	$\delta^{13}C$	SE	Avg. $\delta^{13}C$	SE
032	-10.09	0.04	-10.20	0.00	--	--	-10.15	0.08
033	-9.97	0.02	-9.77	0.03	--	--	-9.87	0.14
034	-9.17	0.01	-9.33	0.05	--	--	-9.25	0.12
035	-9.65	0.01	-9.94	0.04	--	--	-9.80	0.21
036	-10.11	0.04	-10.19	0.01	--	--	-10.15	0.06
037	-9.08	0.01	-9.22	0.06	--	--	-9.15	0.11
038	-10.03	0.06	-9.99	0.03	--	--	-10.01	0.06
039	-8.21	0.02	-8.19	0.03	--	--	-8.20	0.03
040	-10.86	0.01	-10.89	0.00	--	--	-10.88	0.02
041	-9.03	0.04	-9.28	0.02	--	--	-9.16	0.18
042	-10.17	0.06	-10.04	0.03	--	--	-10.11	0.10
043	-9.56	0.02	-9.68	0.02	--	--	-9.62	0.09
044	-14.09	0.05	-14.22	0.01	--	--	-14.16	0.10
045	-10.62	0.11	-10.21	0.02	-9.94	0.06	-10.08	0.20
046	-9.02	0.03	-9.06	0.01	--	--	-9.04	0.04
047	-10.08	0.00	-10.12	0.04	--	--	-10.10	0.04
048	-10.22	0.07	-9.90	0.03	--	--	-10.06	0.23
049	-9.35	0.01	-9.05	0.13	--	--	-9.20	0.23
050	-7.97	0.05	-8.05	0.02	--	--	-8.01	0.07
051	-7.80	0.00	-7.76	0.01	--	--	-7.78	0.03
052	-9.53	0.01	-9.69	0.01	--	--	-9.61	0.11
053	-8.30	0.01	-8.35	0.03	--	--	-8.33	0.04
054	-10.34	0.03	-10.52	0.00	--	--	-10.43	0.13
055	-8.13	0.05	-8.24	0.03	--	--	-8.19	0.09
056	-7.77	0.06	-7.56	0.02	--	--	-7.67	0.16
057	-7.75	0.02	-7.84	0.04	--	--	-7.80	0.07
058	-13.31	0.02	-13.34	0.01	--	--	-13.33	0.03
059	-20.68	0.00	-20.72	0.00	--	--	-20.70	0.03
060	-8.70	0.06	-8.74	0.01	--	--	-8.72	0.05
062	-11.48	0.04	-11.34	0.00	--	--	-11.41	0.10
063	-13.57	0.04	-13.26	0.05	-13.23	0.01	-13.25	0.04
064	-13.41	0.01	-13.47	0.09	--	--	-13.44	0.08

Table 79 (continued).

	Replicate #1		Replicate #2		Replicate #3			
Sample	$\delta^{13}C$	SE	$\delta^{13}C$	SE	$\delta^{13}C$	SE	Avg. $\delta^{13}C$	SE
065	-20.63	0.02	-20.80	0.08	--	--	-20.72	0.13
066	-12.82	0.00	-12.75	0.00	--	--	-12.79	0.05
067	-20.46	0.00	-20.22	0.00	--	--	-20.34	0.17
068	-20.83	0.01	-20.74	0.02	--	--	-20.79	0.07
069	-20.62	0.01	-20.57	0.00	--	--	-20.60	0.04
070	-10.28	0.03	-10.27	0.03	--	--	-10.28	0.03
071	-11.99	0.01	-12.15	0.01	--	--	-12.07	0.11
075	-20.38	0.03	-20.45	0.05	--	--	-20.42	0.06
076	-20.26	0.01	-20.20	0.02	--	--	-20.23	0.05
077	-20.42	0.04	-20.35	0.02	--	--	-20.39	0.06
078	-20.52	0.09	-20.59	0.02	--	--	-20.56	0.08
084	-9.55	0.02	-9.71	0.02	--	--	-9.63	0.11
085	-8.93	0.02	-9.00	0.04	--	--	-8.97	0.06
086	-10.80	0.01	-10.76	0.02	--	--	-10.78	0.03
087	-8.35	0.04	-8.41	0.02	--	--	-8.38	0.05
088	-8.58	0.00	-8.56	0.01	--	--	-8.57	0.02
089	-10.58	0.01	-10.49	0.01	--	--	-10.54	0.06
090	-9.39	0.00	-9.44	0.00	--	--	-9.42	0.04
091	-9.09	0.00	-8.86	0.07	--	--	-8.98	0.17
092	-9.71	0.04	-9.78	0.01	--	--	-9.75	0.06
093	-9.22	0.02	-9.30	0.01	--	--	-9.26	0.06
094	-9.42	0.10	-9.40	0.03	--	--	-9.41	0.08
095	-8.36	0.00	-8.39	0.01	--	--	-8.38	0.02
096	-8.81	0.04	-8.65	0.01	--	--	-8.73	0.12
097	-9.20	0.03	-9.30	0.07	--	--	-9.25	0.09
098	-10.35	0.04	-10.13	0.06	--	--	-10.24	0.16
099	-20.65	0.09	-20.62	0.00	--	--	-20.64	0.07
100	-20.78	0.01	-20.83	0.04	--	--	-20.81	0.05
101	-20.63	0.04	-20.65	0.01	--	--	-20.64	0.03
102	-20.71	0.02	-20.60	0.00	--	--	-20.66	0.08
103	-20.77	0.02	-20.68	0.03	--	--	-20.73	0.07
104	-20.78	0.08	-20.76	0.05	--	--	-20.77	0.07

Table 79 (continued).

	Replicate #1		Replicate #2		Replicate #3			
Sample	$\delta^{13}C$	SE	$\delta^{13}C$	SE	$\delta^{13}C$	SE	Avg. $\delta^{13}C$	SE
105	-20.67	0.04	-20.68	0.02	--	--	-20.68	0.03
106	-20.73	0.04	-21.00	0.12	-20.80	0.01	-20.84	0.16
107	-20.73	0.01	-20.60	0.07	--	--	-20.67	0.10
108	-20.87	0.00	-20.74	0.02	--	--	-20.81	0.09
109	-20.61	0.02	-20.60	0.01	--	--	-20.61	0.02
110	-20.60	0.04	-20.63	0.00	--	--	-20.62	0.04
111	-20.76	0.02	-20.74	0.02	--	--	-20.75	0.02
112	-20.69	0.00	-20.68	0.03	--	--	-20.69	0.02
113	-20.81	0.05	-20.58	0.05	-20.61	0.02	-20.60	0.04
114	-20.49	0.01	-20.52	0.02	--	--	-20.51	0.03
134	-10.05	0.04	-10.00	0.02	--	--	-10.03	0.05
145	-11.13	0.23	-10.60	0.06	-10.87	0.02	-10.87	0.30
147	-9.09	0.12	-8.84	0.03	--	--	-8.96	0.19
148	-8.83	0.00	-8.93	0.01	--	--	-8.88	0.07
149	-10.46	0.01	-10.54	0.01	--	--	-10.50	0.06
150	-9.51	0.01	-9.40	0.01	--	--	-9.46	0.08
151	-9.51	0.01	-9.29	0.03	--	--	-9.40	0.16
152	-8.90	0.05	-9.04	0.01	--	--	-8.97	0.11
153	-20.92	0.00	-20.79	0.04	--	--	-20.86	0.10
154	-20.50	0.01	-20.62	0.13	--	--	-20.56	0.13
156	-20.78	0.00	-21.55	0.10	-21.80	0.04	-21.68	0.19
158	-20.95	0.01	-20.98	0.01	--	--	-20.97	0.02
159	-20.73	0.01	-20.77	0.01	--	--	-20.75	0.03
160	-20.84	0.00	-20.82	0.10	--	--	-20.83	0.07
163	-21.41	0.14	-21.95	0.14	-21.82	0.00	-21.89	0.12
164	-20.71	0.02	-20.72	0.02	--	--	-20.72	0.02
170	-9.80	0.02	-9.94	0.02	--	--	-9.87	0.10
181	-10.94	0.08	-11.58	0.03	-11.85	0.02	-11.45	0.47
184	-9.50	0.01	-9.45	0.03	--	--	-9.48	0.04
186	-10.20	0.02	-10.15	0.00	--	--	-10.18	0.04
190	-9.62	0.04	-9.56	0.02	--	--	-9.59	0.05
198	-9.43	0.02	-9.38	0.03	--	--	-9.41	0.04

Table 79 (continued).

	Replicate #1		Replicate #2		Replicate #3			
Sample	$\delta^{13}C$	SE	$\delta^{13}C$	SE	$\delta^{13}C$	SE	Avg. $\delta^{13}C$	SE
200	-8.11	0.14	-8.27	0.05	--	--	-8.19	0.15
202	-8.19	0.03	-8.27	0.07	--	--	-8.23	0.08
206	-8.82	0.01	-8.72	0.00	--	--	-8.77	0.07
209	-9.14	0.01	-9.22	0.01	--	--	-9.18	0.06
211	-10.09	0.04	-10.03	0.00	--	--	-10.06	0.05
214	-11.02	0.04	-10.96	0.02	--	--	-10.99	0.05
215	-11.19	0.01	-11.42	0.05	--	--	-11.31	0.17
219	-9.99	0.06	-10.01	0.00	--	--	-10.00	0.04
220	-10.29	0.03	-10.35	0.03	--	--	-10.32	0.05
224	-10.73	0.05	-10.98	0.04	-11.52	0.02	-11.08	0.41
227	-9.77	0.01	-9.75	0.02	--	--	-9.76	0.02
228	-10.26	0.12	-10.02	0.02	--	--	-10.14	0.19
229	-20.36	0.07	-20.80	0.03	-20.34	0.00	-20.35	0.04
230	-10.32	0.03	-10.42	0.04	--	--	-10.37	0.08
231	-9.28	0.04	-9.23	0.01	--	--	-9.26	0.05
232	-20.62	0.02	-20.60	0.02	--	--	-20.61	0.02
234	-20.59	0.01	-20.66	0.00	--	--	-20.63	0.05
235	-20.48	0.00	-20.82	0.01	-20.61	0.03	-20.64	0.17
236	-20.2	0.03	-19.96	0.01	-20.14	0.01	-20.10	0.13
237	-20.52	0.13	-20.39	0.00	--	--	-20.46	0.13
238	-11.76	0.03	-12.01	0.00	--	--	-11.89	0.18
240	-8.70	0.03	-8.75	0.06	--	--	-8.73	0.06
241	-10.85	0.01	-10.63	0.02	--	--	-10.74	0.16
242	-20.44	0.01	-20.49	0.04	--	--	-20.47	0.05
243	-9.46	0.01	-9.46	0.00	--	--	-9.46	0.01
244	-11.19	0.01	-11.30	0.02	--	--	-11.25	0.08
245	-20.51	0.06	-20.34	0.03	--	--	-20.43	0.13
246	-11.33	0.05	-11.43	0.03	--	--	-11.38	0.08
247	-20.50	0.01	-20.38	0.01	--	--	-20.44	0.09
248	-20.32	0.08	-20.37	0.00	--	--	-20.35	0.07
249	-9.28	0.05	-9.01	0.05	--	--	-9.14	0.20
250	-9.76	0.01	-9.72	0.05	--	--	-9.74	0.05

Table 79 (continued).

	Replicate #1		Replicate #2		Replicate #3			
Sample	$\delta^{13}C$	SE	$\delta^{13}C$	SE	$\delta^{13}C$	SE	Avg. $\delta^{13}C$	SE
251	-10.39	0.03	-10.48	0.00	--	--	-10.44	0.07
252	-10.15	0.03	-10.17	0.03	--	--	-10.16	0.03
253	-9.88	0.01	-9.86	0.00	--	--	-9.87	0.02
254	-9.16	0.00	-9.09	0.04	--	--	-9.13	0.06
255	-9.77	0.05	-9.70	0.01	--	--	-9.74	0.06
256	-20.12	0.03	-20.12	0.05	--	--	-20.12	0.04
258	-20.41	0.08	-20.48	0.06	--	--	-20.45	0.09
259	-20.26	0.00	-20.5	0.05	--	--	-20.38	0.17
260	-9.88	0.02	-9.89	0.01	--	--	-9.89	0.02
261	-19.04	0.05	-19.04	0.02	--	--	-19.04	0.04
262	-19.19	0.03	-18.89	0.02	--	--	-19.04	0.22
263	-20.65	0.04	-20.67	0.01	--	--	-20.66	0.03
264	-15.79	0.00	-15.72	0.01	--	--	-15.76	0.05
268	-18.29	0.07	-18.31	0.03	--	--	-18.30	0.06
269	-13.94	0.01	-13.93	0.02	--	--	-13.94	0.02
274	-13.85	0.02	-13.84	0.04	--	--	-13.85	0.03
275	-14.38	0.01	-14.35	0.02	--	--	-14.37	0.03
286	-8.11	0.02	-8.05	0.03	--	--	-8.08	0.05
288	-9.58	0.03	-9.23	0.07	-8.53	0.01	-9.11	0.54
289	-9.14	0.05	-8.92	0.04	--	--	-9.03	0.16
291	-8.48	0.04	-7.95	0.31	-8.07	0.01	-8.01	0.20
293	-10.65	0.03	-9.81	0.04	-9.87	0.01	-9.84	0.05
296	-10.52	0.15	-10.19	0.05	--	--	-10.35	0.26
297	-8.79	0.05	-8.87	0.03	--	--	-8.83	0.07
298	-10.28	0.03	-8.40	0.06	-8.26	0	-8.33	0.11
299	-8.17	0.02	-7.99	0.04	--	--	-8.08	0.13
300	-9.51	0.01	-9.49	0.03	--	--	-9.50	0.03
301	-8.72	0.05	-8.74	0.00	--	--	-8.73	0.04
302	-11.31	0.05	-10.89	0.11	-10.95	0.01	-10.92	0.08
303	-10.28	0.06	-10.00	0.14	-10.71	0.04	-10.33	0.37
304	-10.05	0.01	-9.95	0.01	--	--	-10.00	0.07
307	-8.87	0.04	-9.14	0.03	-9.61	0.01	-9.21	0.37

Table 79 (continued).

	Replicate #1		Replicate #2		Replicate #3			
Sample	$\delta^{13}C$	SE	$\delta^{13}C$	SE	$\delta^{13}C$	SE	Avg. $\delta^{13}C$	SE
315	-8.91	0.01	-8.84	0.03	--	--	-8.88	0.05
327	-8.71	0.02	-8.65	0.02	--	--	-8.68	0.05
339	-19.96	0.04	-20.05	0.01	--	--	-20.01	0.07
340	-20.08	0.03	-20.27	0.08	--	--	-20.17	0.14
341	-20.23	0.02	-20.37	0.02	--	--	-20.30	0.10
342	-20.00	0.03	-20.17	0.01	--	--	-20.09	0.12
343	-20.05	0.01	-19.93	0.01	--	--	-19.99	0.09
344	-20.23	0.02	-20.39	0.02	--	--	-20.31	0.11
345	-20.19	0.01	-20.27	0.00	--	--	-20.23	0.06
346	-20.07	0.04	-20.09	0.00	--	--	-20.08	0.03
347	-20.41	0.04	-20.22	0.00	--	--	-20.32	0.14
348	-20.27	0.05	-20.35	0.02	--	--	-20.31	0.07
350	-20.10	0.06	-20.21	0.00	--	--	-20.16	0.09
351	-19.95	0.02	-19.99	0.03	--	--	-19.97	0.04
353	-20.03	0.06	-20.22	0.06	--	--	-20.13	0.15
354	-20.29	0.01	-20.26	0.01	--	--	-20.28	0.02
356	-10.70	0.02	-10.88	0.00	--	--	-10.79	0.13
357	-10.45	0.05	-10.31	0.03	--	--	-10.38	0.11
358	-10.14	0.07	-9.98	0.03	--	--	-10.06	0.13
359	-11.28	0.00	-11.14	0.02	--	--	-11.21	0.10
360	-11.15	0.01	-11.05	0.00	--	--	-11.10	0.07
361	-11.98	0.04	-11.88	0.05	--	--	-11.93	0.08
362	-10.97	0.01	-11.09	0.04	--	--	-11.03	0.09
363	-10.12	0.05	-9.63	0.13	-9.91	0.09	-10.01	0.16
364	-12.92	0.01	-12.89	0.03	--	--	-12.91	0.03
365	-11.6	0.02	-11.57	0.01	--	--	-11.59	0.03
366	-9.86	0.02	-9.74	0.00	--	--	-9.80	0.09
367	-10.98	0.02	-11.02	0.02	--	--	-11.00	0.03
368	-10.53	0.01	-10.69	0.09	--	--	-10.61	0.13
369	-11.31	0.01	-11.53	0.06	--	--	-11.42	0.16
371	-10.49	0.11	-10.09	0.07	-10.61	0.01	-10.55	0.11
372	-12.3	0.03	-12.40	0.02	--	--	-12.35	0.07

Table 79 (continued).

	Replicate #1		Replicate #2		Replicate #3			
Sample	$\delta^{13}C$	SE	$\delta^{13}C$	SE	$\delta^{13}C$	SE	Avg. $\delta^{13}C$	SE
373	-20.13	0.07	-20.08	0.00	--	--	-20.11	0.06
377	-13.72	0.04	-13.59	0.05	--	--	-13.66	0.10
379	-14.56	0.00	-14.35	0.03	--	--	-14.46	0.15
380	-12.57	0.03	-13.08	0.03	-13.08	0.02	-13.08	0.02
382	-9.68	0.04	-9.53	0.00	--	--	-9.61	0.11
383	-20.44	0.01	-20.24	0.01	--	--	-20.34	0.14
384	-10.16	0.09	-10.04	0.00	--	--	-10.10	0.11
385	-12.40	0.03	-12.43	0.00	--	--	-12.42	0.03
386	-12.79	0.02	-12.35	0.04	-12.17	0.04	-12.26	0.13
387	-12.44	0.03	-12.57	0.02	--	--	-12.51	0.10
388	-12.83	0.03	-12.86	0.01	--	--	-12.85	0.03
389	-12.94	0.04	-12.57	0.04	-12.55	0.04	-12.56	0.05
400	-10.50	0.01	-10.51	0.05	--	--	-10.51	0.04
402	-10.90	0.01	-10.80	0.01	--	--	-10.85	0.07
403	-10.80	0.03	-10.65	0.00	--	--	-10.73	0.11
404	-10.32	0.02	-10.35	0.01	--	--	-10.34	0.03
408	-10.61	0.01	-10.66	0.01	--	--	-10.64	0.04
416	-10.61	0.03	-10.57	0.00	--	--	-10.59	0.04
417	-10.55	0.01	-10.29	0.05	--	--	-10.42	0.18
418	-10.95	0.00	-10.98	0.04	--	--	-10.97	0.04
419	-8.30	0.03	-8.40	0.03	--	--	-8.35	0.08
420	-7.63	0.01	-7.65	0.01	--	--	-7.64	0.02
421	-7.80	0.01	-7.72	0.01	--	--	-7.76	0.06
422	-7.66	0.03	-7.68	0.01	--	--	-7.67	0.03
423	-7.86	0.10	-8.01	0.06	--	--	-7.94	0.13
424	-7.04	0.01	-7.07	0.02	--	--	-7.06	0.03
425	-8.65	0.11	-8.79	0.01	--	--	-8.72	0.13
426	-7.70	0.00	-7.81	0.03	--	--	-7.76	0.08

APPENDIX G: EXPERIMENTAL OBSERVATIONS ON THE EFFECTIVENESS OF ACETIC ACID TREATMENT ON REMOVING ALTERED BONE MINERAL

Dilute acetic acid treatment is commonly used in efforts to remove contaminating materials from archaeological and paleontological bones prior to isotopic and trace element analysis of bone mineral. This strategy relies on the observation that diagenetically-altered apatites often incorporate amounts of carbonate or fluoride from the soil solution that differ from the original bioapatite. Different compositions differentially affect the solubility of the apatites (Sillen and LeGeros 1991); carbonate substitutions increase solubility, while fluoride substitutions decrease it. Thus, the acetic acid pretreatments are designed to remove more-soluble secondary carbonates and apatites with higher carbonate composition, both frequent products of diagenesis. Although specific protocols vary among observers, there are two main approaches in current use. For trace element analysis, particularly strontium-calcium ratios (Sr/Ca), powdered bone is treated with a series of fifteen to twenty quick (one minute) washes with dilute (0.1 M), buffered acetic acid (Sillen 1989). For analysis of stable carbon isotopes, bone is subject to a dilute (1.0 M) acetic acid soak over several (usually 24 – 48) hours (Krueger 1991; Lee-Thorp and van der Merwe 1991). With the former technique, researchers measure the composition of the solutes produced; with the latter, they measure the composition of the powdered residue.

Attempts to visually observe the effectiveness of dilute acetic acid pretreatments on archaeological bone specimens from the Ohio Valley are described here. This required some modification to the approach as described in the literature. The general strategy was to use electron imaging of polished thick-sections of bone to document changes in the bone resulting from acetic acid pretreatment according to the following protocol: (1) backscattered electron (BSE) images were acquired using a JEOL Environmental Scanning Electron Microscope

(ESEM) for several points on each specimen prior to treatment; (2) specimens were subject to a series of five washes (each wash consisting of sonication for one minute in 20 ml 0.1 M acetic acid/sodium acetate buffer at pH 4.5); (3) specimens were rinsed in nanopure water; (4) BSE images were collected at the points imaged in step 1; and (5) steps 2 – 4 were repeated twice more. In all, each specimen was treated by 15 washes and four sets of images were collected to document the appearance of specimens before, during and after the treatment. Because thick sections have a lower surface area than bone powder, I did not expect to observe the same degree of dissolution that would characterize standard protocols; however, a similar pattern should be evident. Obviously altered areas (e.g., destructive foci) should be preferentially removed, while structurally-intact (and potentially chemically-unaltered) areas should exhibit less etching by the acid.

Before looking at archaeological bone samples, I established that the acid treatment did not attack the epoxy in which bones would be embedded. Epoxy samples were documented using backscattered electron (BSE) imaging before, during and after treatment. As Figure 178 shows, after 15 washes the embedding medium shows slight deterioration. The outline of previous raster patterns on the final epoxy image suggests that this deterioration is probably an artifact of the electron beam. Because epoxy is not conductive, it is susceptible to beam damage resulting from high temperatures caused by prolonged rastering of the beam at one location. Minimizing the amount of time spent collecting images at each point should reduce the impact of beam damage on the samples.

My next step was to similarly treat a carbonate to determine if the lower surface area of thick sections (compared to powdered specimens typically used) would permit an observable level of dissolution. Also of concern was the possibility that the distribution of epoxy might influence sample dissolution, perhaps slowing the rate of dissolution in its immediate vicinity. Coral specimens were embedded in epoxy, thick-sectioned, polished, and subjected to the acetic acid

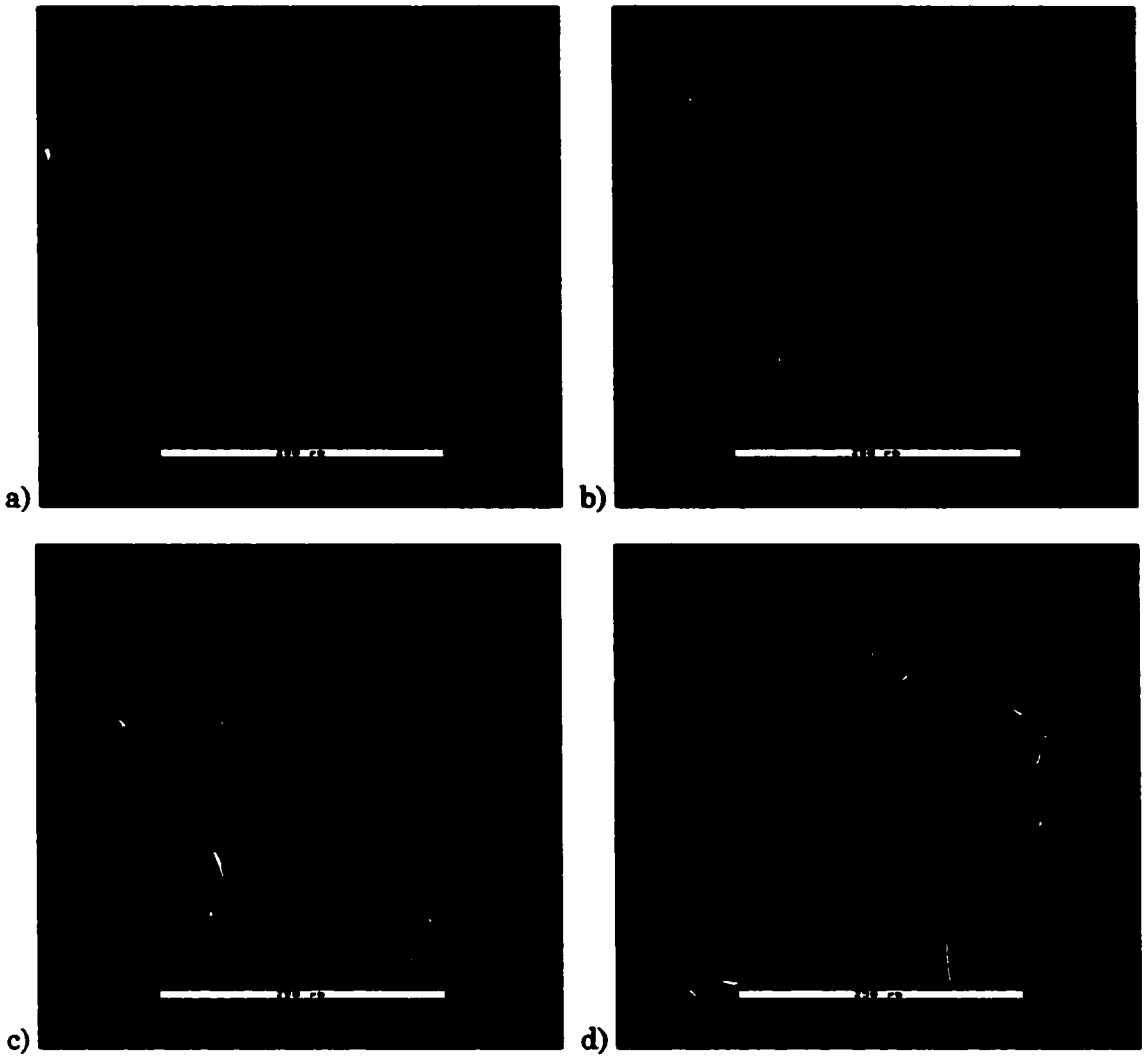


Figure 178. **Backscattered electron (BSE) images of epoxy.** The location is identified by an "x" incised into the surface. (a) prior to treatment, (b) after 5 acetic acid washes, (c) after 10 washes, and (d) after 15 washes.

treatment. As shown in Figure 179, observable amounts of carbonates are removed by the acetic acid treatment and epoxy does not appear to structure the rate of dissolution. The rate of dissolution may be slightly higher along sample edges, probably reflecting greater surface areas in those places.

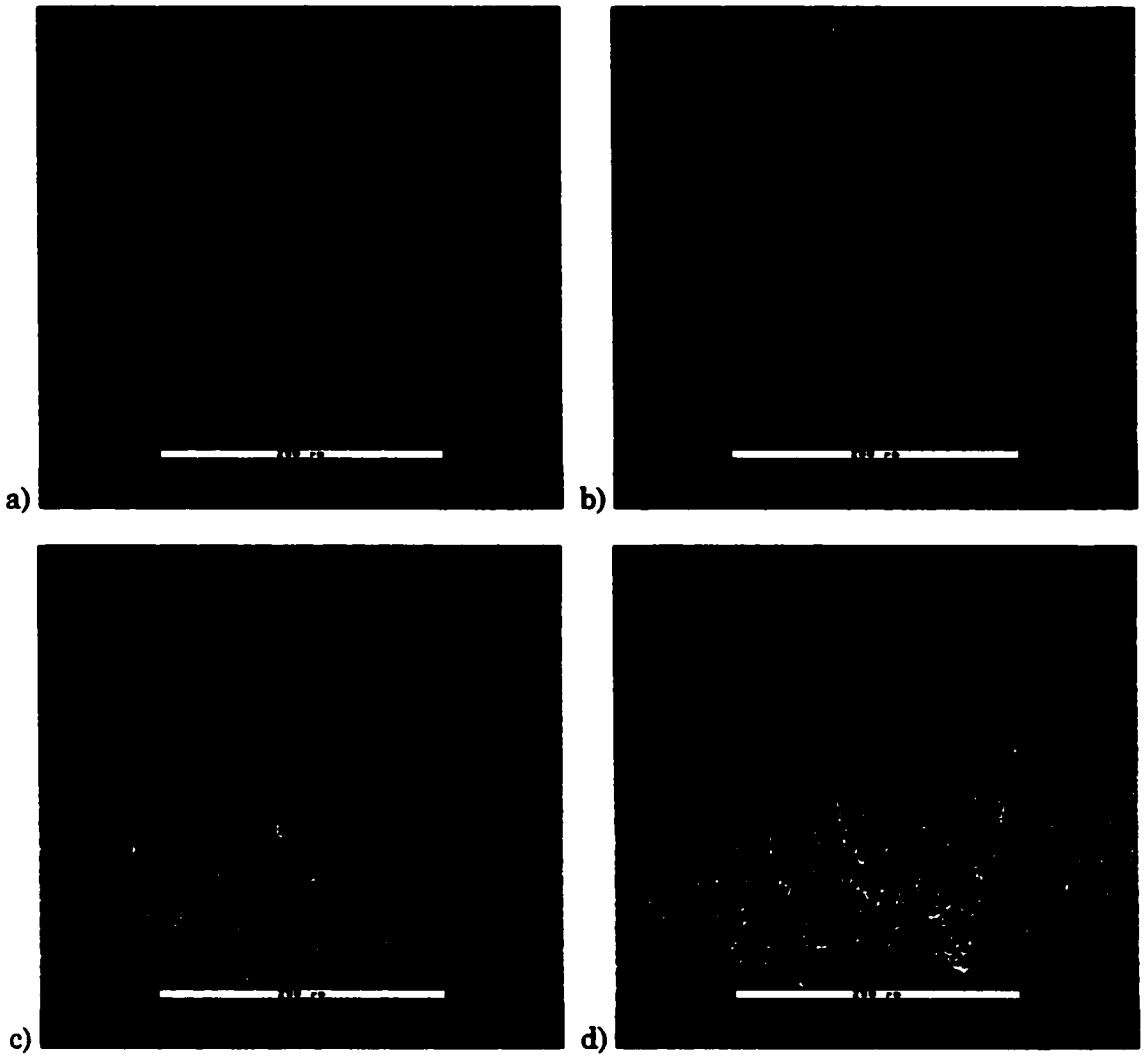


Figure 179. **BSE images of coral.** (a) prior to treatment, (b) after 5 acetic acid washes, (c) after 10 washes, and (d) after 15 washes.

Modern human bone was then subject to the acetic acid treatment. I wanted to determine if the treatment had a significant impact on unaltered bone and, if it did, what the nature of that impact was. Previous experiments using modern bone have suggested on the basis of chemical analyses that adsorbed carbonates and perhaps some bone mineral are removed and that the chemical composition of the bone is altered by acetic acid treatment (Lambert et al. 1990; Lee-Thorp and van der Merwe 1991). Figure 180 shows clearly that the treatment

does dissolve modern bone and that it does so unevenly. It is also quite clear that dissolution follows the histological structure of the bone; as with the epoxy, a slight raster pattern is visible, but the slight amount of beam damage does not diminish the obvious pattern of loss. The rate of dissolution appears to be determined by the age of the bone; "age" refers to the relative order of mineral deposition. Areas of

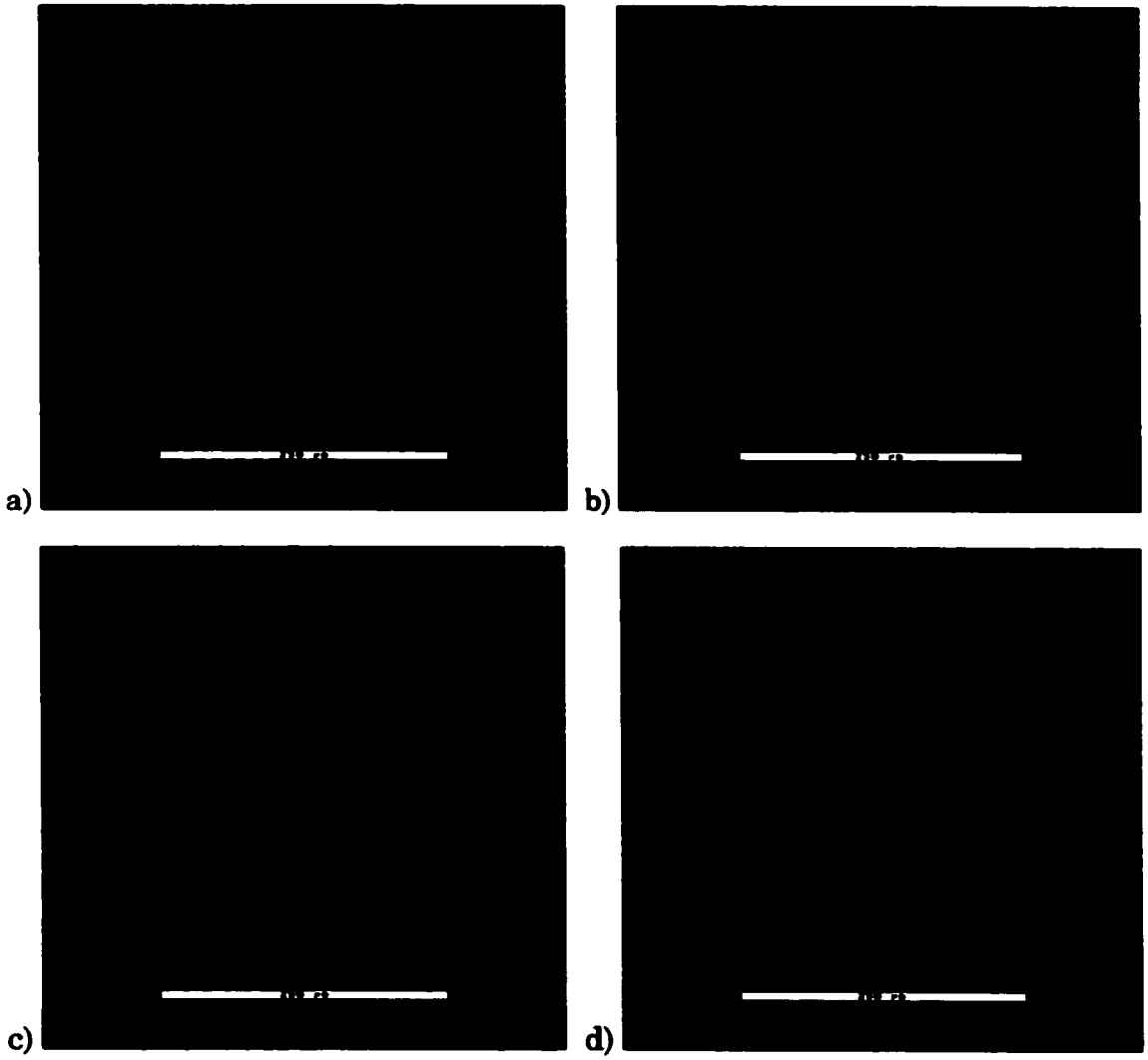


Figure 180. **BSE images of modern bone.** (a) prior to treatment, (b) after 5 acetic acid washes, (c) after 10 washes, and (d) after 15 washes.

more recent deposition (new bone) appear to have been etched at a faster rate than those deposited earlier (old bone). This probably reflects subtle differences in the crystallinity, surface area and chemistry of the bone mineral.

Although not conclusively established, bone mineral deposition probably begins with the precipitation of an amorphous calcium phosphate precursor (Posner 1987; Simkiss 1975). Over time, the amorphous phase is converted to extremely small hydroxyapatite crystals, which then grow in size. The smaller crystals of newly-formed bone tend to be slightly calcium-depleted and they tend to have more ionic substitutions (e.g., Sr) than mature bone (Posner 1987). These nonstoichiometric variations cause structural disruptions and tend to make immature bone more soluble. In addition, smaller crystals have a larger surface area available for chemical reaction than the larger crystals of more mature bone. As a consequence of this greater solubility and surficial reactivity, one might anticipate that newer bone might be more easily dissolved by the acetic acid treatment.

To the extent that newly deposited bone has a different chemical composition than mature bone, alterations to bone chemistry may result from acetic acid treatment. Adsorbed carbonates, which appear to be removed by acetic acid treatment, comprise about half of the bone carbonate pool (Posner 1987). Structural carbonate (which substitutes for phosphate ions) is probably unevenly distributed among apatite crystals, tending to be less common in larger, more mature crystals. Crystals with greater carbonate content are structurally distorted and hence, less stable and more easily dissolved by the treatment. As long as there are no differences in the isotopic compositions of carbonates that are adsorbed or associated with the different phases of bone mineral, however, $\delta^{13}C$ values should remain unaltered by acetic acid treatments. Significant changes ($t = 6.012$; $p = .004$) in the isotopic composition of bioapatite in modern bone before and after treatment have been documented, however, in experiments using the 1.0 M acetic

acid soak (Lee-Thorp and van der Merwe 1991). Whatever is going on, it is clear that acetic acid treatments will remove biogenic carbonates from bone.[80]

Finally, the impact of the acetic acid treatment on archaeological bone was examined. My primary concern here was to see if diagenetically altered areas (identified here as alterations to the histological structure of bone) were removed from these archaeological bones by the treatment. As Figure 181 shows, obviously altered areas like destructive foci are not the first fractions to be dissolved. Indeed, the bone that shows the greatest structural integrity appears to be the first removed, while structurally amorphous areas and the "rinds" around the destructive foci both appear to resist dissolution. This same pattern has been observed in other bone specimens, as well.

Figure 182 presents a similar series of images collected at higher magnification. That the "rinds" around the destructive foci are more resistant to dissolution is quite clear in this figure. Compositional analysis of several points using energy dispersive spectrometry (EDS) and wavelength dispersive spectrometry (WDS) on a JEOL 733 Superprobe microprobe revealed that the "rinds" of the destructive foci are composed of calcium phosphate; the structurally amorphous material (located on the exterior surface of the bone visible at the top of Figure 182) is a pyrolusite-rich (i.e., high manganese and iron) calcium phosphate.

This is not the pattern expected if the acetic acid treatment was effectively removing diagenetically-altered apatite. Thus far, however,

---

[80] Although little is known about the trace element chemistry of bone, it is known that, in the process of crystal growth, Sr tends to be replaced by Ca (Posner 1987). Thus, the preferential removal of immature bone (and adsorbed ions) by acetic acid treatment may also have a significant impact on subsequent trace element analyses. This is seemingly supported for some elements at least (but not clearly so for Sr/Ca) by experimental work (cf. Lambert et al. 1990).

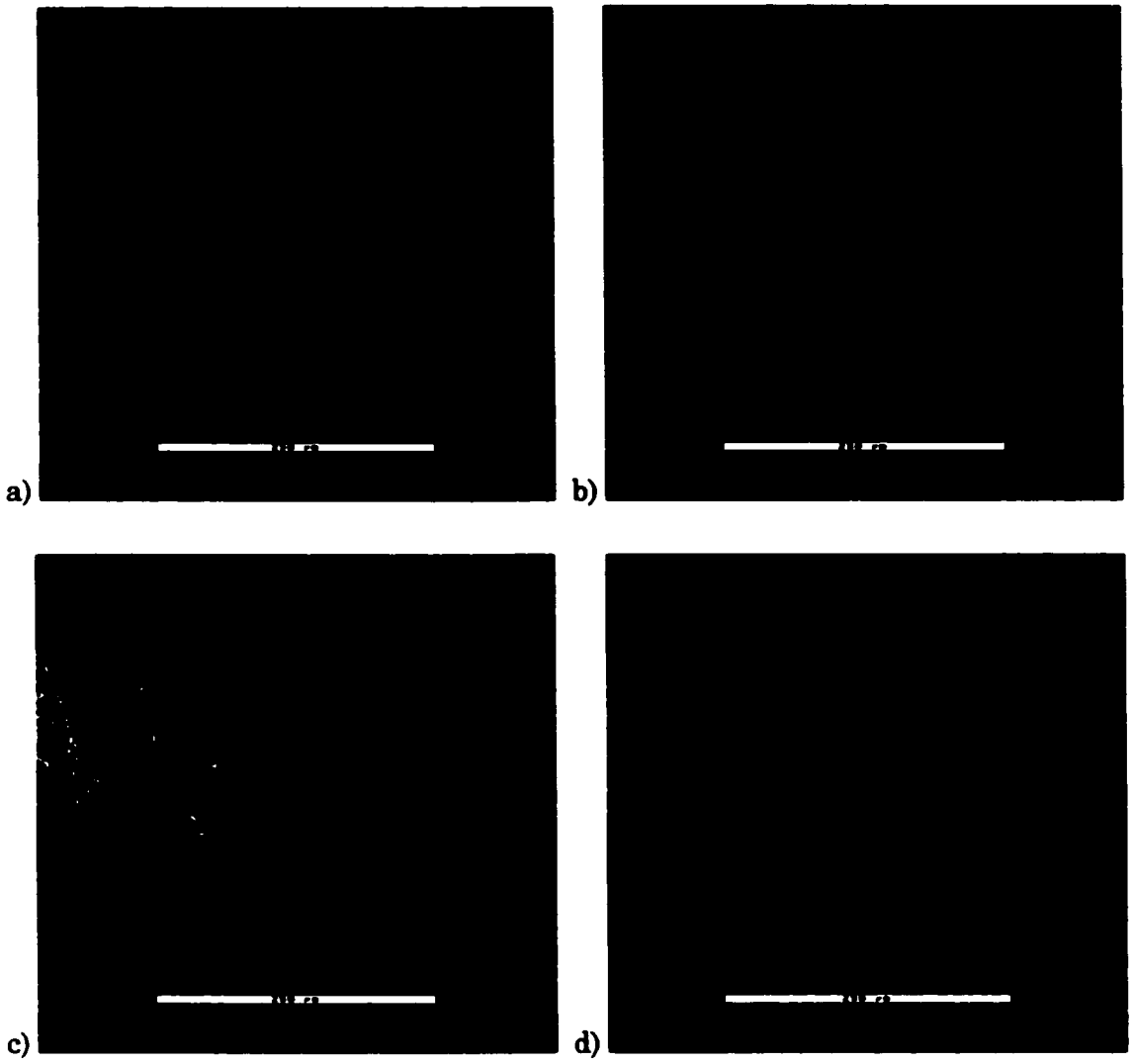


Figure 181. BSE images of archaeological bone (sample 153, from Chilton). (a) prior to treatment, (b) after 5 acetic acid washes, (c) after 10 washes, and (d) after 15 washes.

embarrassingly few (n = 3) archaeological specimens have been examined in this time-consuming way. Importantly, too, the consequences of these observations on the isotopic and/or trace element composition of the materials have yet to be determined. As a consequence, no general conclusions about the efficacy of acetic acid treatment prior to chemical analysis are warranted with respect to

archaeological samples from the Ohio Valley or elsewhere. The reason I present these preliminary results here, though, is to make the point that it should not simply be assumed, as many have done, that acetic acid treatments have successfully removed contaminants and left biogenic signatures of prehistoric diet intact. Convincing demonstrations to that effect are required.

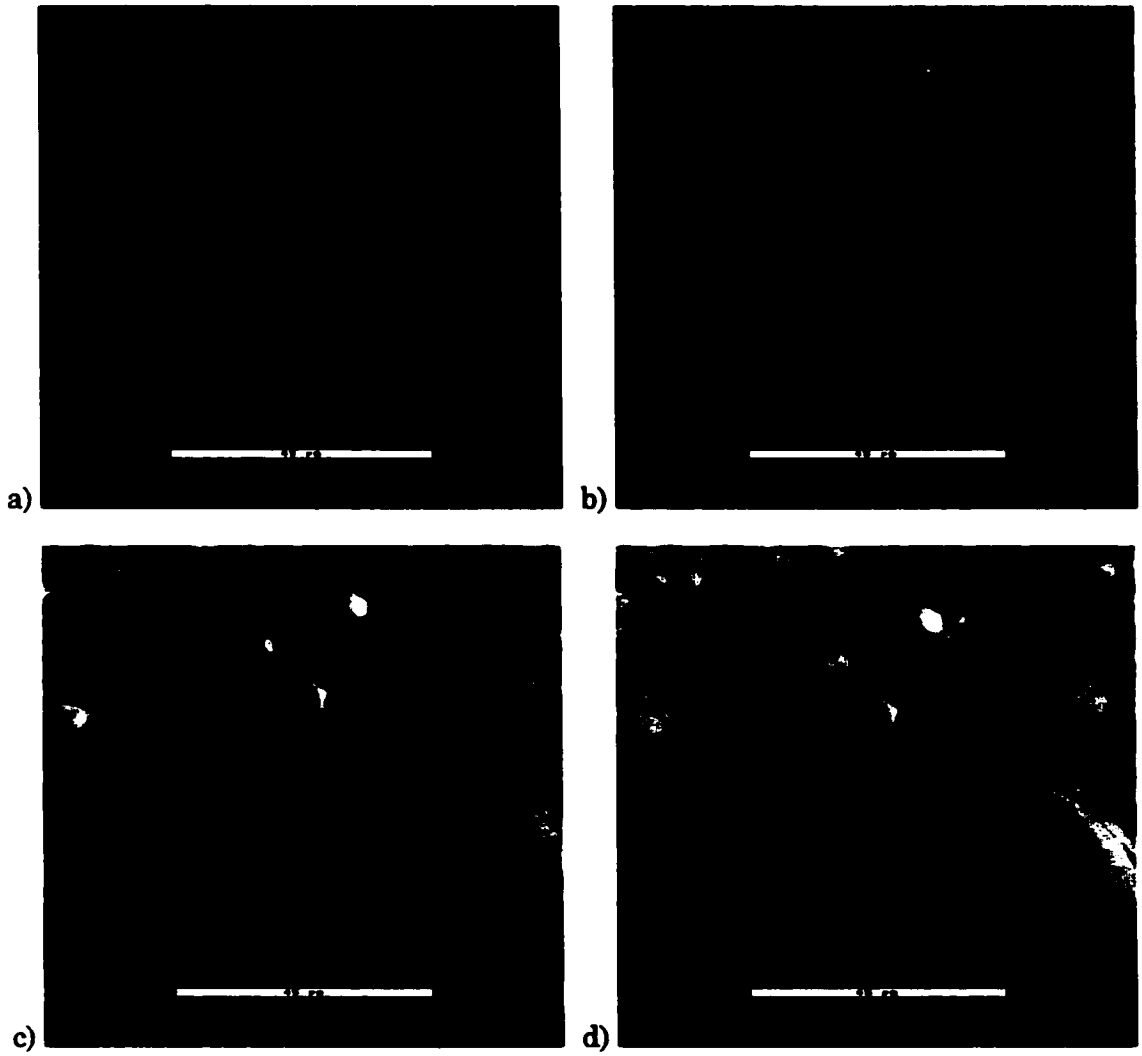


Figure 182. **Higher magnification images of same bone shown in Figure 181.**

APPENDIX H: ANALYSIS OF SOIL DATA

One hypothesis advanced to account for variation in $\delta^{13}C$ values among different populations is that the soils cultivated by those groups may have differed with respect to the growing requirements for maize and thus, in the yields produced and consumed. In particular, because $\delta^{13}C$ values for populations inhabiting the Till Plains appear to be lower than in other parts of the study region, it was suggested that the soils of the Till Plains may differ from the soils elsewhere. As a group, they do differ. Soils of the Till Plains are younger and they tend to be less well-developed than in areas to the south and east; many Till Plain soils are formed in glacial till and they tend toward greater compactness than soils formed in other parent materials (McLoda and Parkinson 1980). It is not clear, however, how relevant these properties may have been to prehistoric maize productivity.

Archaeological analyses of the impact of soils on Amerindian maize cultivation in eastern North America have explicitly considered properties such as slope, soil texture and drainage (Heidenreich 1971; Nass 1988; Sykes 1980). For example, in his consideration of Late Prehistoric farmers of southwest Ohio, Nass assumed that swidden farmers did not use (1) soils on slopes >12% because they are prone to erosion, (2) soils with high clay content because the available technology was not well-suited to their cultivation, or (3) poorly-drained soils because they may result in plant loss. Others (e.g., George 1974) have assumed that soil fertility was also a critical variable that determined what soils were cultivated.

There is ethnographic evidence that slopes >>12% are cultivated. For example, swidden plots of the Machiguenga of Amazonia are often sloped from 36 – 84 % (Johnson 1983), while those of the Luá of Thailand have slopes up to 70% (Kunstadter 1978); similarly, Conklin (1957) documented slopes ranging from 40 – 63 % for individual swidden plots of the Hanunóo of the Philippines, and within

plots, slopes ranged from 10 – 84 %. Thus, steep slopes do not appear to be limiting for swidden farming.

Ethnographic reports also document that soils with significant clay content are successfully cultivated using swidden techniques. For example, among the Hanunóo, clayey soils (including clay, silty clay, sandy clay, and clay loam textures [the latter two being best suited for growing grains]) are cultivated using only dibbles, planting sticks and digging sticks (Conklin 1957). Thus, the technology available to Late Prehistoric farmers of the Ohio Valley was sufficient for cultivating clayey soils. Even so, accepting that the available technology was up to the task of cultivating clayey soils does not mean soil texture was an unimportant variable. Cultivating clayey soils likely involves greater costs (greater effort may be required to clear the primary vegetation, to prepare the plot and to plant crops) than with other soil types. Finally, the impact of soil texture on crop yield must be considered; soil drainage is a critical variable for maize growth.

Assumptions about the role of soil fertility in prehistoric maize farming systems have led some to argue that some soils either were not utilized or were used only when better soils were not available. For example, recall from Chapter Two, George's (1974) suggestion that upper Ohio Valley populations lived in upland settlements and farmed distant, but fertile, valley soils. Turning again to ethnographic observations, Gross (1983) found no evidence that soil fertility was a limiting factor among native groups of central Brazil in determining what soils would be cultivated.

Similarly, archaeologists reconstructing swidden agricultural systems commonly assume that garden plots were abandoned because of declining crop yields due to decreasing soil fertility (e.g., Sykes 1980). This is not necessarily true (Carneiro 1960). Indeed, ethnographic research has often found a poor correlation between declining crop yields and decreasing soil fertility (Moran 1983). Instead, such research consistently documents that the most important determinant of when

gardens are allowed to fallow is weed and/or secondary forest regeneration (Carneiro 1983; Conklin 1957; Moran 1983; Rappaport 1971). Increasing numbers of tree seedlings and more aggressive invasion by grasses make gardening activities more difficult and less profitable each year (Johnson 1983). Plots are used until it becomes more expensive to weed the current garden than it would be to clear new land. In addition to increasing weeding labor costs, the longer a plot is in continuous cultivation, the greater the risk that other factors like pests, disease and grassland development pose (Moran 1983).

GROWING REQUIREMENTS OF MAIZE

Four basic soil properties are consistently identified in the contemporary agronomic literature as important determinants of maize yields: drainage, moisture content, pH and nitrogen availability.

Apparently, maize is particularly susceptible to conditions of poor drainage. Poorly drained soils may require a delay in planting, which may result in significantly decreased yields (Nolte and Duvick 1986). Once planted, excessively wet soils inhibit plant growth through oxygen deprivation, increased levels of soil CO_2, and reduced microbial activity (Palmer and Fausey 1986). Presumably, good soil drainage was as much a requirement for prehistoric varieties of maize as it is for modern varieties. Since soil compaction decreases both drainage and aeration (Steinhardt and Griffith 1992) and results in lower crop productivity, there is some basis behind the notion that soil variation may account for differences in prehistoric maize consumption across the study region.

Even as maize requires well-drained soils, though, it also needs sufficient soil moisture throughout the growing season. Agronomic studies have shown that no-till strategies result in higher levels of soil moisture content due to increased water infiltration (by decreasing runoff) and decreased evaporation. Because swidden systems have a minimum impact on soil structure and they retain

a protective coating of ashes and incompletely burned plant material over the plot, I assume here that (excluding excessively drained soils) maintaining sufficient soil moisture was less of a problem for prehistoric maize farmers than for modern ones.

Another soil property identified as significantly impacting maize productivity by contemporary farmers is pH (Nelson et al. 1992). Yields among modern varieties of maize are greatest when soil pH is slightly acid to neutral (6.2 – 7.0). Soil pH determines the availability of critical soil nutrients (e.g., P), as well as potentially toxic elements (e.g., Al, Mn). Specifically, conditions of neutral pH maximize P availability and minimize toxic elements like Al and Mn. Although most soils in the study region tend toward strong acidity, burning (as a step in swidden plot preparation) acts to increase soil pH (Ahlgren and Ahlgren 1960; Gross 1983), as well as to liberate nutrients from the living plant biomass (especially potassium). Although burning would have at least partly mitigated the effects of acidic soil pH levels on crop yields, pH probably remained an important factor in determining the maize yield potential of soils.

With respect to nitrogen availability, it is a problem for contemporary farmers, particularly where land is intensively cultivated year after year, where inadequate crop rotation sequences are used, and where minimal crop residues are left in the fields. Since the bulk of soil nitrogen is obtained from organic matter, burning may increase or decrease nitrogen availability, depending upon the severity of the burn. Increased pH levels produced by burning encourage bacterial activity, which results in increased nitrification (Ahlgren and Ahlgren 1960). In addition, the ethnohistorically-documented practice among Eastern Woodlands natives of intercropping nitrogen-fixing beans with maize could have been beneficial for the maize crop (Heidenreich 1971). Thus, I assume here that nitrogen availability was less critical for maize crops prehistorically than it is today.

SOIL PROPERTIES AND MAIZE YIELDS

Analyses of soil properties associated with archaeological deposits typically rely on recent soil surveys. I have suggested previously (Greenlee 1990) that soil surveys of the early 1900s are more relevant than recent ones to considerations of prehistoric soil properties because they better reflect the condition of soils prior to the intensive application of Euroamerican farming techniques, including drainage, liming, fertilization and mechanized tilling. Even though it is easily appreciated how such soil management practices might have, over the long term, altered soil properties, it is important to remember that, even at the time of the first soil surveys, much land had been under cultivation for many decades and the soil descriptions by no means reflect aboriginal conditions. For example, a 1902 report on soils of the Columbus, OH, area (Smith 1903) remarked that artificial drainage improvements had begun in the 1860s; what were naturally very poorly-drained soils had become, by 1902, the most productive corn soils in that area. The early soil descriptions may provide the best data, but even those data must be reviewed carefully.

Other factors, both positive and negative, also need to be weighed in deciding which surveys to use. Early soil surveys (arbitrarily limited here to those predating 1940) are strongly oriented toward providing information about the agricultural potential of different soils, and the soil units are defined accordingly. In contrast, more recent surveys are also concerned with other uses; the soil units are substantially more complex. The scales at which the soil units are mapped are considerably smaller for the early surveys than for the more recent ones (typical scales are 1:62,500 vs. 1:15,840, respectively). The soil descriptions in the early surveys are also less precise than in more recent reports. While recent surveys pretty consistently report numerical estimates for soil properties (e.g., pH, available moisture capacity), most early ones provide only verbal descriptions (e.g., "rather acid"). The early surveys do not uniformly discuss pH and drainage for all soil types either, but those data can often be teased from comments about the parent material,

natural vegetation, soil texture and structure. Finally, the early reports are more limited in geographic coverage within the study region than more recently conducted surveys. In spite of these limitations, I rely on the early surveys because they provide data more relevant to the issue of soil variation and prehistoric maize cultivation.

As a simple check of how closely soil pH, drainage and maize yields were related historically, I compared those data for a sample of five counties within the study region. For each county, each soil type was classified as to pH and drainage (Table 80); Kruskal-Wallis tests were used to evaluate whether corn yields (generally the midpoint of a reported range in yields as bushels/acre) were distributed similarly across the different classes. Results are presented in Table 81. Clearly, soil properties as reported in the early soil surveys influenced maize yields[81] and they did so in a predictable way. Although the growing requirements of prehistoric varieties of maize are unknown, I assume here that they were similar to historic varieties with respect to soil pH and drainage.

DETERMINING CATCHMENT SIZE

Although the Till Plains may have a greater proportion of more poorly-drained soils (because of their greater compaction) than in other areas in the study region, it is not certain that prehistoric farmers were actually using the poorly-drained ones. Instead, it is more likely that they nonrandomly used the better-drained soils of the area; if well-drained soils suitable for maize were relatively limited there though, one outcome might have been a lower dietary

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[81] As an aside, similar analyses using recent soils surveys produced more variable results. I expected that, with greater levels of soil management and more varieties of maize available for cultivation in more recent times, the relationship between soil pH, drainage and yields might become less predictable. This seems to be the case. Of ten counties examined, average yields varied significantly across the soil classes for only two counties.

Table 80. Classification of soil properties.

A. pH
1. Acid: extremely acid to medium acid
2. Neutral: slightly acid to mildly alkaline
3. Alkaline: moderately alkaline to very strongly alkaline
B. Drainage
1. Good: well drained to moderately well drained
2. Fair: moderately well drained to somewhat poorly drained, *or* somewhat excessively drained
3. Poor: somewhat poorly drained to very poorly drained, *or* excessively drained
C. Soil Class (combined pH and drainage)
1. Good: pH neutral to alkaline with good drainage
2. Fair: pH acid with good drainage, *or* pH neutral to alkaline with fair drainage
3. Poor: pH acid with fair drainage, *or* pH acid to alkaline with poor drainage

commitment to maize. To compare the soils between the Till Plains and other parts of the study region, then, requires that only the soils surrounding each archaeological locale be considered.

Catchment analysis involves determining the distance individuals travel to obtain resources and the distribution of those resources within that territory (Higgs and Vita-Finzi 1972; Vita-Finzi and Higgs 1970). Because they differ in terms of their return rates, different resources will be exploited in catchment territories of different size (cf. Hastorf 1980). Here, of course, I am concerned with the catchment territory used for maize-farming and the distribution of soils within that territory. Determining the size of the catchment territory over which the relative contribution of different soil classes should be estimated is not a

simple question. As the size of the defined catchment area varies, so too may the relative composition of soils within it (cf. Sykes 1980). Thus, defining the size of the relevant catchment territory is a problem that has important consequences.

Table 81. Variation in historic maize yields across drainage, pH and soil class. Significant results at $\alpha = .05$ are in boldface.

	Drainage		pH		Soil Class	
County & (Reference)	χ^2	p	χ^2	p	χ^2	p
Hamilton, OH (Goodman et al. 1919)	5.591	.061	5.131	.077	**6.897**	**.032**
Indiana, PA (Avon Burke et al. 1931)	0.472	.492	**10.027**	**.002**	**8.584**	**.003**
Hancock/Brooke/Ohio, WV (Caine and Tailby 1908)	**5.445**	**.020**	**4.235**	**.040**	**7.059**	**.029**
Mason/Jackson/Putnam, WV (Latimer and Mooney 1912)	4.504	.105	2.235	.327	**6.072**	**.048**
Logan/Mingo, WV (Latimer 1916)	4.955	.084	**3.850**	**.050**	5.455	.065

Ethnographic observations have demonstrated, in accordance with economic principles, that both the time invested in and the net yield from crops decrease with distance from settlements (Chisholm 1979). It is more costly to farm distant plots because travel time must be factored into the equation. Because plants differ with respect to the amount of time their cultivation requires and the net yields they produce, zones of land use result. How far individuals travel to cultivate particular crops is a function of several factors, including the importance of the resource in the subsistence system, the distribution of soils, physical geography, settlement permanence, population size and population density.

When defining catchment areas, archaeologists have routinely drawn on published ethnographic observations. There is a large range in average distances between settlement and farmed plots, with some as low as 0.3 Km and others as high as 6.0 Km, but most tend to be within 2.0 Km (Chisholm 1979). Since the ethnographic record is so variable, it is not surprising that the catchment radii used by archaeologists have varied, as well. The values used previously by researchers on problems related to prehistoric maize farming in eastern North America range from 1.00 to 3.22 Km (Greenlee 1990; Morse 1981; Nass 1988; Sykes 1980).

In determining an appropriate catchment radius for this research, I found two ethnographic observations particularly enlightening. First, data compiled from Finland about the net return of crops in plots at varying distance from settlements (Chisholm 1979) show that they decline logarithmically; by a distance of 2.5 Km, the net returns are roughly 30% or less of the yields within 0.1 Km of the settlement. Second, roughly 70% of agricultural trips made by Kofyar farmers are within 0.7 Km of their dwellings, with less than 5% being 2.5 Km or greater (Stone 1991). Although neither of these observations are directly relevant to questions of prehistoric farming in the Eastern Woodlands, they suggest that a catchment radius of 2.5 Km likely encompasses the area that received the bulk of the farming effort and reaped the greatest crop yields. Although it probably varied somewhat depending upon the circumstances under which each locale was occupied, a catchment radius of 2.5 Km is assumed here to be adequate for exploring variation in the soils available for farming.

Early (pre-1940) soil maps were scanned for each of fifteen archaeological locales (Table 82); each locale has associated stable carbon isotope data and sufficient geographic information that it could be pinpointed on the early maps. As Figure 183 shows, five of the locales are on the Till Plains in

southwestern Ohio and the rest are distributed across the Unglaciated Allegheny Plateau (four in the Upper Valley, two in southern Ohio and four in the southern

Table 82. Archaeological locales and early soil surveys.

Archaeological Locale	Reference
O. C. Voss	Smith 1903
Incinerator	Dorsey and Coffey 1901
Campbell Island	Fowler and Green 1927
Schomaker	Fowler and Green 1927; Goodman et al. 1919
Turpin	Goodman et al. 1919
Childers	Latimer and Mooney 1912
Killen	Taylor et al. 1938
Feurt	Conrey et al. 1940
Man	Latimer 1916
Barkers Bottom	Kerr 1929
Johnston	Avon Burke et al. 1931
Duvall	Caine and Tailby 1908
Hughes Farm	Caine and Tailby 1908
46OH13	Caine and Tailby 1908
Roseberry Farm	Latimer and Mooney 1912

half of West Virginia). The three soil classes defined in Table 80 were identified and traced; a series of increasingly larger catchment territories (with radii increasing by 0.5 Km increments up to 2.5 Km) was added to each map. Figure 184 shows a sample of catchment maps. For those locales bordering the Ohio and Conemaugh Rivers, territory on the opposite side of the river was not included in the catchment analysis; although people may have crossed the smaller streams and rivers to farm, it is assumed here that they did not cross the large rivers for that purpose.

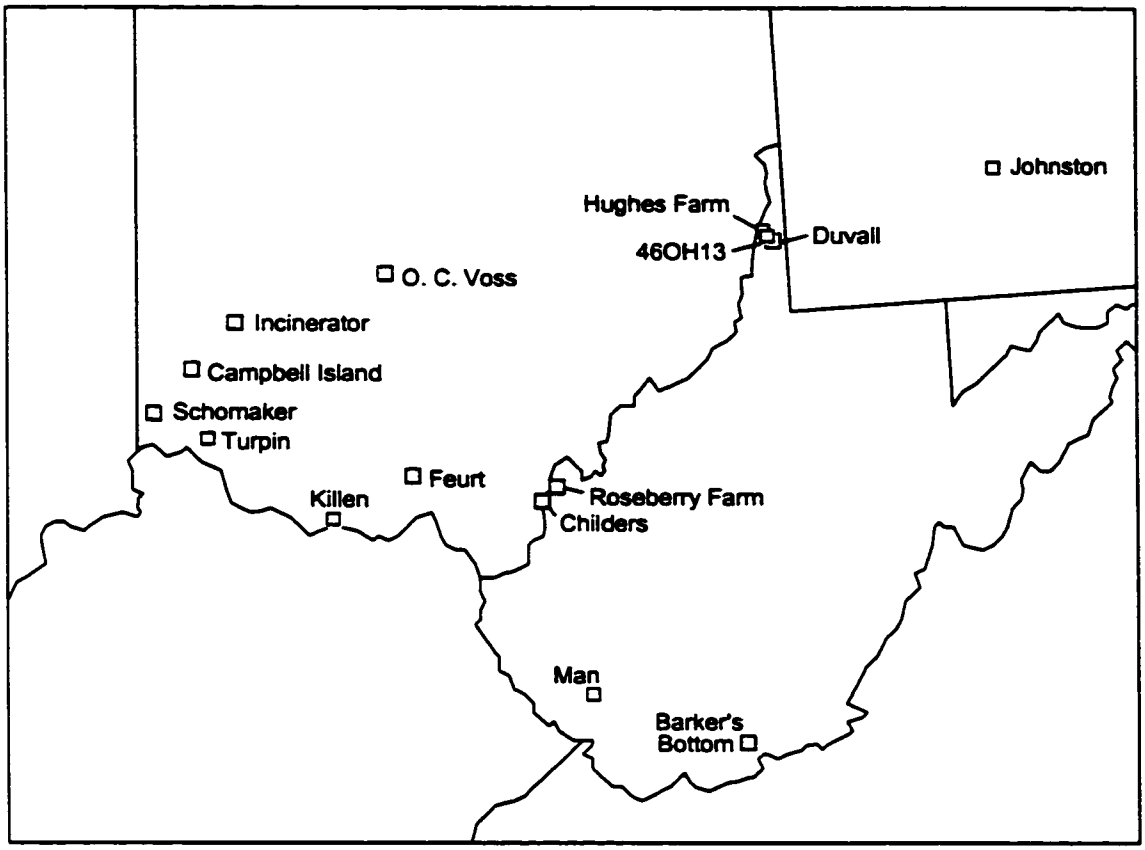


Figure 183. **Archaeological locales for which catchment maps were generated that depict the distribution of soil classes.**

The area covered by each soil class in each increasingly larger catchment territory was measured for each locale using Scion Image software. Then, the relative proportion of the soil classes was calculated and plotted for each. Figure 185 presents these plots for each of the fifteen locales examined here. The plots are arranged with those in the left column being the Till Plains locales; the top four of the right column are Upper Valley locales and the rest are from southern Ohio and the southern half of West Virginia. At first glance, it is clear that the relative abundance of the different soil classes varies greatly among these locales, but without any clear geographic patterning. Interestingly, among the Till Plains locales, the two with soils derived from Late Wisconsin drift (O.C. Voss and

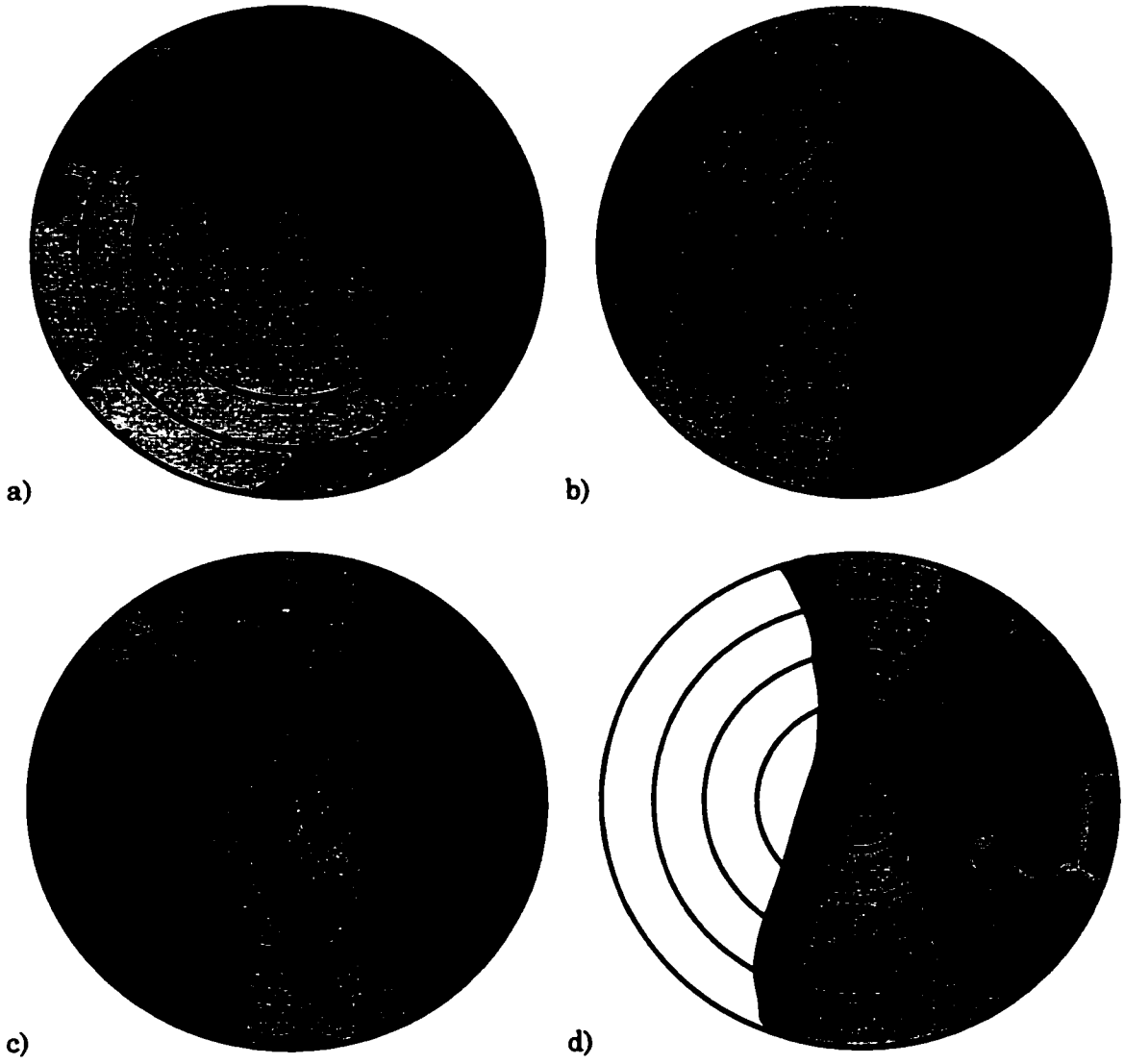


Figure 184. **Soil classes in catchment territories surrounding archaeological locales.** (a) Duvall, (b) Feurt, (c) O. C. Voss, and (d) Childers. Light gray indicates "good" (Class 1) soils, medium gray indicates "fair" (Class 2) soils, and dark gray indicates "poor" (Class 3) soils; black indicates river water.

Incinerator) appear to have higher proportions of Class 3 "poor" soils than the other three with soils derived from Early Wisconsin and Illinoian drift.

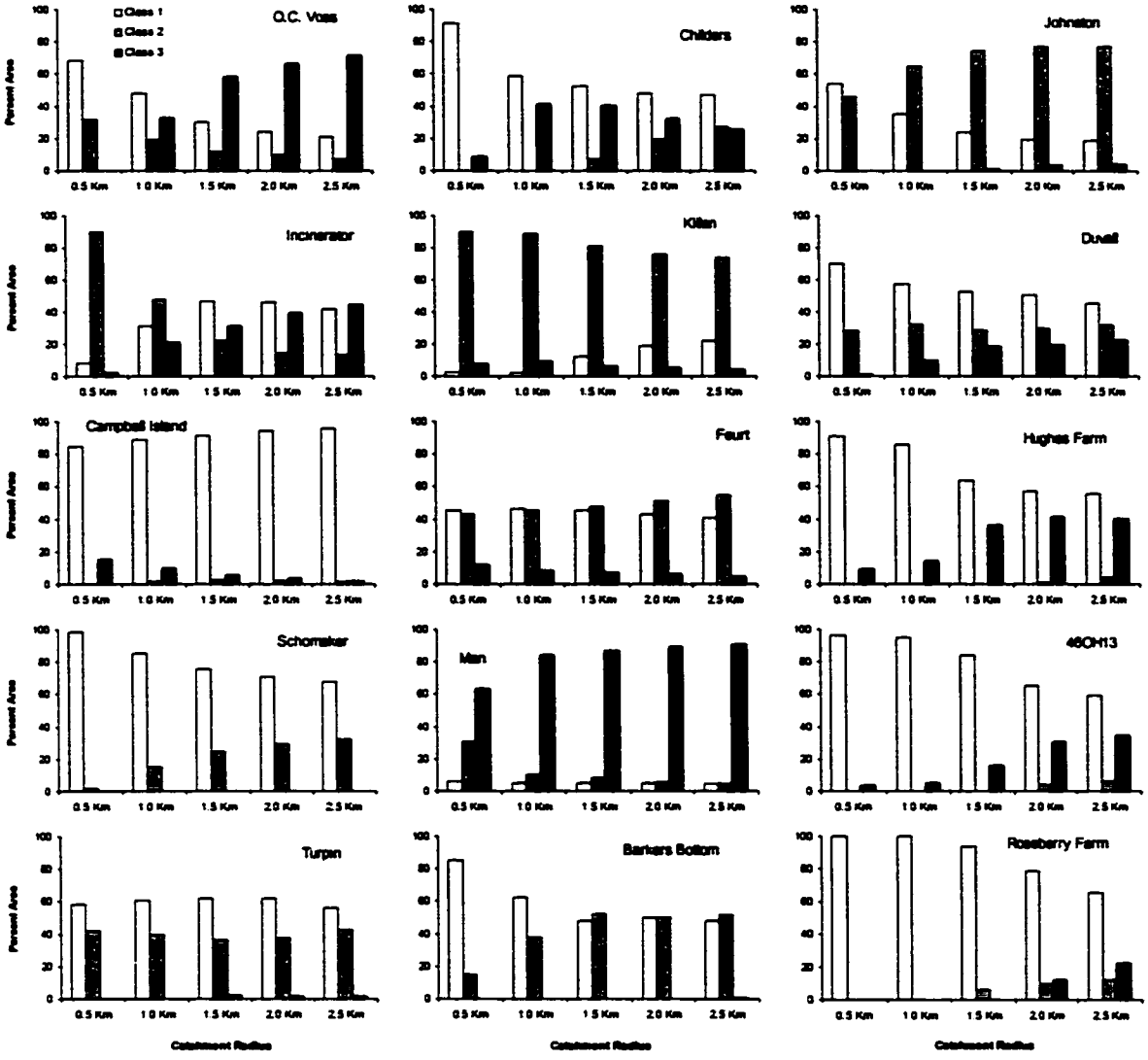


Figure 185. Distribution of soil classes with catchment size for Ohio Valley locales. Class 1, "good" soils; Class 2, "fair" soils; and Class 3, "poor" soils.

At the same time, it is also clear that the selection of catchment radius could have varying impacts on the estimation of the relative availability of the different soil classes. For some locales, there is considerable change in the composition of soils as the catchment size increases, while for others there is little variation. The majority of settlements are located such that the highest proportion of Class 1 "good" soils are within a 0.5 Km radius; the contribution of good soils

either decreases or remains constant as the catchment radius increases for 80% of the locales. I note, however, that the relative contribution of different soil classes appears to stabilize by roughly 2.0 – 2.5 Km for most locales.

SOIL COMPARISON

As might be expected from examining the plots in Figure 185, the distribution of soils surrounding locales of the Till Plains do not differ statistically from those elsewhere in the study region. Kruskal-Wallis tests to compare the proportion of Class 1 "good" soils in 2.5 Km catchments of Till Plains and other locales indicate that these samples could have come from the same population (χ^2 = 1.215; p = .270). The other four catchment radius sizes were examined as well and similar results were obtained. Thus, based on this sample and using these assumptions about soil quality, there is no evidence that, as a group, soils of the Till Plains surrounding archaeological settlements were less-suited for maize cultivation than elsewhere in the study region.

I note also that mean $\delta^{13}C$ values for these fifteen locales were found to correlate significantly and negatively with the proportion of Class 1 "good" soils in the catchment (Table 83). Individuals located in areas with high proportions of soils that should have been well-suited for maize cultivation tended to consume less maize than those surrounded by lower proportions of those soils. Such a finding runs counter to intuitive anthropological assumptions about how ancient people related to their landscape. It is, however, indirectly supported by earlier research (Greenlee 1990) that found higher levels of maize consumption among individuals surrounded by lower proportions of arable land (in that work, arable land was defined as land with a slope $\leq$ 8%). Although warranting further investigation, it appears that those situations most suitable for maize production were well-suited for other resources, as well.

Table 83. Rank correlations between mean $\delta^{13}C$ value and proportion of Class 1 "good" soils in catchments of various radii for fifteen archaeological locales. Results significant at $\alpha = .05$ are in boldface.

Catchment Radius (Km)	ρ	p
0.5	**-.586**	**.022**
1.0	**-.514**	**.050**
1.5	-.482	.069
2.0	**-.511**	**.052**
2.5	**-.532**	**.041**

APPENDIX I: THE RECORD OF CLIMATIC CHANGE

Climate is generally considered a statistical description of daily weather events over a specific time period and for a particular place (Houghton et al. 1996).[82] As a statistical expression, climate can be characterized in terms of central tendency and variance for one or more of several parameters (e.g., temperature, precipitation, wind speed and direction, or cloudiness). Both the central tendency and the variance of climatic parameters are important to understanding its (climate's) impact on ecological productivity and human subsistence.

Although many parameters of climate are recognized, ecologists consistently note the importance of two in assessing plant productivity, temperature and humidity. Thus, those two parameters are most relevant to this research. Since there are no direct measures of these parameters in prehistory, climate proxy records are critical to documenting past climate. Past climate can be estimated from climate proxy records because they are the products of biological, chemical and geological processes that were influenced by climatic conditions. In this research, climatic proxy data (pollen, beach ridge and tree ring records, and borehole temperature profiles) and macrophysical climatic models are used to determine the timing and nature of climatic change that might have occurred in the study area over the past 2000 years. Since each kind of proxy record has unique strengths and weaknesses (Table 84), the best conclusions are produced when multiple records are used (cf. Nicholls et al. 1996).

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[82] Bryson and Bryson (1997b) argue, however, that climate is more than a statistical summation of weather – it is also the thermodynamic state of the atmospheric, biospheric, hydrospheric, and cryospheric systems that determines weather patterns. Macrophysical climatic modeling relies on the thermodynamics of changing "climatic states" to reconstruct past climates.

PALYNOLOGICAL RECORDS

Using pollen analysis to reconstruct past climatic conditions relies on establishing the nature of several complex relationships: between climate and the composition of vegetation, between the abundance of vegetation and the pollen

Table 84. Strengths and weaknesses of different sources of climatic information.

Data Source		Strengths and Weaknesses
Pollen Cores	Strengths:	Geographic dispersion of records around Eastern N.A. Cores with varves well-dated Based on relation between vegetation and climate Reflect growing season climatic parameters
	Weaknesses:	Subregional to local scale Relatively few cores from study region Few samples analyzed over time period of interest Cores lacking varves often poorly-dated Unknown "lag" period in response to climate change Response may vary with topography, soils, location in range, etc.
Beach Ridges	Strengths:	Reflect conditions of relative humidity
	Weaknesses:	Regional scale, restricted to areas north of study region Difficult to establish age of features Specifics of causal conditions unclear, averaged across drainage basin Local conditions may influence nature and preservation of beach ridge features
Tree Rings	Strengths:	Site specific data Growing season humidity/temperature reflected Data available on annual scale Chronological resolution excellent
	Weaknesses:	No samples of relevant age in study region
Borehole Profiles	Strengths:	Site specific data Potentially direct measure of ground surface temperature
	Weaknesses:	No boreholes in study region Chronological resolution poor Detail increasingly poor with greater age Average annual temperature
Macrophysical Models	Strengths:	Site specific data are provided
	Weaknesses:	Climatic simulations are only crude approximations Assumes historic weather patterns can be extended into past

produced, and between the abundance of pollen produced and the abundance of pollen recovered in lake and/or bog sediments. These relationships are knowable quantitatively only to the extent that they can be documented in modern plant studies (Birks and Birks 1980; Birks and Gordon 1985; Faegri and Iversen 1975) and there remain several unresolved issues (e.g., how to distinguish migrational limits from climatic ones; how to establish specific vegetational responses to changes in specific climatic parameters; how vegetational responses to climate are mitigated by topography, soils, and/or reproduction rates). Still, pollen analysis provides minimally a means to determine the timing and direction of past climatic changes and maximally a means to establish the magnitude of those changes.

For this research, the primary problem with the majority of published palynological analyses is one noted previously by Griffin (1960) and echoed by others (e.g., Gajewski et al. 1987) – that most analysts are concerned with major climatic changes and are not particularly interested in the subtle changes that characterize the past 2000 years. Thus, sampling intervals over the most recent 2000 years are typically so coarse that only a few samples represent this time frame from any given core. Additionally, this segment of most cores is rarely dated directly; the age of these sediments is typically estimated through linear interpolation between an often much earlier ^{14}C date and a historic marker, such as the surface or the rise in ragweed (*Ambrosia*) pollen that is everywhere assumed to accompany Euroamerican disturbance.

Figure 186 locates and Table 85 lists a subset of the published palynological records for central and eastern North America. Sediment cores that (1) are not dated directly and so must rely on profile comparisons with other cores, (2) do not have reliable dates in the range 2000 ± 1000 BP to tie down the early end of the past 2000 years in longer cores, (3) do not provide detailed information about this time period because that portion of the core is missing, is sparingly analyzed (represented by 20 or fewer samples) or is unanalyzed, or (4) show evidence of any

impact due to prehistoric human landscape disturbance, are omitted. These criteria eliminated scores of potential data sources, but those palynological records that met the criteria provide the best possible data set for resolving high frequency climatic changes during the past 2000 years. Unfortunately, only five of the sequences cover the entire time span; three span less than 2000, but more than 1500 years; and the remainder cover the past 1000 years or so.

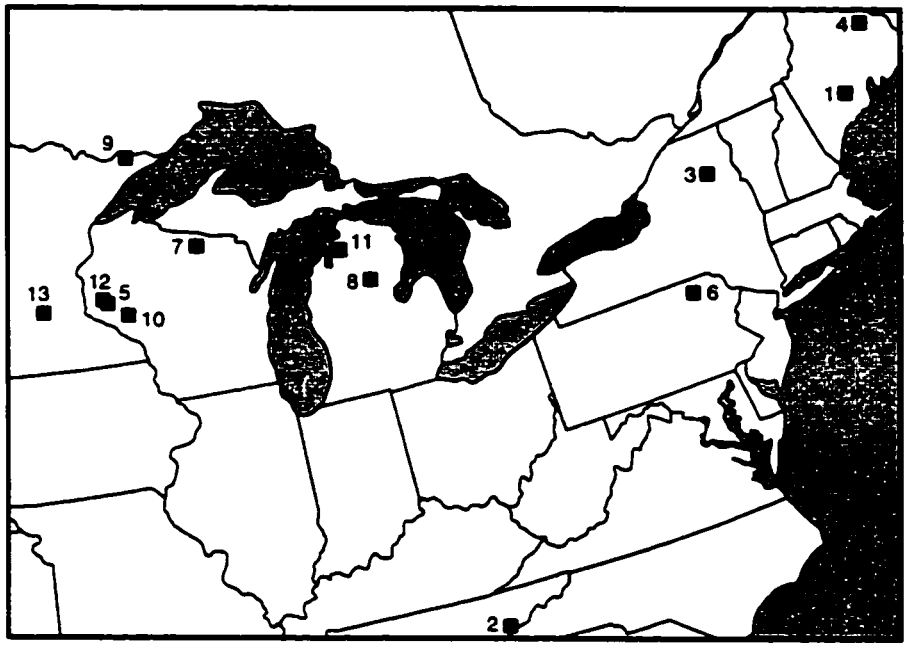


Figure 186. **Location of relevant palynological records.** Numbers correspond to core sites listed in Table 85.

As Table 85 indicates, seventy percent of the sediment cores considered here were dated using varves, which are laminations appearing as alternating light and dark bands. The pollen and diatoms of these bands indicate that their deposition is a seasonal event, with light bands being formed in the late spring and early summer and dark bands being formed in the autumn, winter and early spring (Tippett 1964). Thus, the laminae are comprised by annually-deposited couplets. When this fine-scale stratigraphy is preserved, varve counts provide a more precise estimate of age than radiocarbon dating.

As Figure 186 shows, the palynological records considered here are all located north of the study region, except for Black Pond in Tennessee. The geographic dispersion of the cores has implications for understanding climatic change because an episode of climatic change may not be expressed in the same way across all cores. That is, a particular suite of taxa may not be equally informative

Table 85. Palynological cores used in this study, their dating strategy, and the number of samples younger than 2000 BP analyzed from each.

#	Name	Dating Strategy	# of Samples	References
1	Basin Pond, ME	Varves	56	Gajewski et al. 1987
2	Black Pond, TN	^{14}C	37	Delcourt et al. 1986
3	Clear Pond, NY	Varves	48	Gajewski et al. 1987
4	Conroy Lake, ME	Varves	68	Gajewski et al. 1987
5	Dark Lake, WI	Varves	39	Gajewski et al. 1985
6	Ely Lake, PA	Varves	36	Gajewski et al. 1987
7	Hells Kitchen Lake, WI	Varves	73	Swain 1978
8	Jones Lake, MI	^{14}C	23[a]	Bernabo 1981
9	Lake of the Clouds, MN	Varves	45[a]	Swain 1973
10	Little Pine Lake, WI	Varves	33	Gajewski et al. 1985
11	Marion Lake, MI	^{14}C	27[a]	Bernabo 1981
12	Ruby Lake, WI	Varves	36	Gajewski et al. 1985
13	Rutz Lake, MN	^{14}C	21	Waddington 1969

[a] estimated from pollen diagrams

about climatic conditions across all pollen sites. First, the composition of the local vegetation varies greatly from site to site – trees dominating one locale may not even be present elsewhere. Second, there is bound to be some "slop" simply because trees in the middle of a taxon's range may not respond to a climatic change as quickly or to the same degree as those located near the edge of the range – there may be variation in the "lag" between climatic and vegetation change. Third, local factors such as soil characteristics may influence the relative response of the vegetation to changing climatic conditions. Consequently, taxa which are good indicators of climatic change must be identified for each core on an individual basis.

Of the pollen records listed in Table 85, pollen counts are available in the North American Pollen Database (which is part of the World Data Center - A for Paleoclimatology, administered by the Paleoclimatology Program of the National Oceanic and Atmospheric Administration [NOAA], and the data are accessible at http://www.ngdc.noaa.gov/paleo/) for ten sites and reconstructed estimates of summer temperature and annual precipitation are available for six of those. Those sequences can then be compared with other relevant pollen records for which such data are not available. The geographic distribution (with four sites located east of the Great Lakes, five to the west of the Great Lakes, and one to the south) will allow not only vegetational change associated with regional climatic events to be examined, but more importantly, synchronous events consistent with climatic change across eastern North America can be documented. Such large-scale climatic events are likely to have occurred in the Ohio Valley, as well.

MESIC INDEX

Because the nature of climatic change over the past 2000 years in eastern North America is fairly subtle, three different climatic parameters (mesic index, summer temperature and annual precipitation) derived from the available pollen records are considered. The mesic index is calculated as:

$$\Sigma \text{ Cool/Wet Tree Taxa} \div \Sigma \text{ (Cool/Wet + Warm/Dry Tree Taxa)} \times 100.$$

The first step in estimating the mesic index is determining, for each of the ten pollen records with available data, which tree taxa are most likely to indicate cool and/or wet, as opposed to warm and/or dry, climatic conditions (Table 86). At this level of analysis, only whether these taxa respond to cooler and/or wetter conditions *or* warmer and/or drier conditions can be distinguished; hence, the use of cool/wet (= mesic) and warm/dry (= xeric) descriptives. With few exceptions, data were not available for taxa below the generic level; thus, in situations where relevant genera contain multiple species having significantly different ecological tolerances, those genera were excluded. Logically, the relative frequencies of cool/wet and warm/dry classes should be negatively, but not necessarily significantly, correlated. As Table 87 shows, this is the case for all of the records but one, Black Pond; for this reason, it is excluded from further consideration of variation in the mesic index.

Table 86. Cool/wet and warm/dry tree taxa for each pollen core.

	Cool/Wet Taxa	Warm/Dry Taxa
Basin Pond	*Acer, Fagus, Fraxinus, Picea, Tsuga, Ulmus*	*Pinus banksiana/resinosa, P. strobus, Quercus*
Black Pond	*Fagus, Fraxinus, Juglans, Ostrya/Carpinus*	*Carya, Castanea, Quercus*
Clear Pond	*Acer, Fagus, Fraxinus, Picea, Tsuga, Ulmus*	*Carya, Pinus strobus, P. banksiana/resinosa, Quercus*
Conroy Lake	*Acer, Fagus, Fraxinus, Larix, Picea, Tsuga, Ulmus*	*Pinus banksiana/resinosa, P. strobus, Quercus*
Dark & Hell's Kitchen Lakes	*Acer, Ostrya/Carpinus, Tsuga, Fraxinus, Ulmus*	*Populus, Quercus*
Ely Lake	*Acer, Fagus, Fraxinus, Tilia, Tsuga, Ulmus*	*Carya, Castanea, Pinus banksiana/resinosa, P. strobus, Quercus*
Little Pine & Rutz Lakes	*Acer, Fraxinus, Tilia, Tsuga, Ostrya/Carpinus, Ulmus*	*Populus, Quercus*
Ruby Lake	*Acer, Tilia, Tsuga, Ulmus*	*Populus, Quercus*

The relationship between the mesic index and the number of tree and herb pollen grains counted (number of identified specimens or NISP) was examined to establish whether sample size might influence the value of the index. As shown in Table 87, the mesic index of Basin Pond is correlated with sample size and it has been excluded from further consideration of variation in the mesic index.

Table 87. The nature and significance of correlation coefficients between the relative frequencies of cool/wet (mesic) and warm/dry (xeric) taxa and between the Mesic Index and number of identified specimens (NISP) for ten pollen records.

	% Mesic vs. % Xeric Taxa		Mesic Index vs. NISP	
	ρ^a	p	ρ	p
Basin Pond	**−.472**	**<.001**	**.389**	**.003**
Black Pond	.107	.496	.188	.228
Clear Pond	**−.450**	**.001**	−.194	.187
Conroy Lake	**−.282**	**.020**	−.152	.215
Dark Lake	−.243	.136	−.237	.147
Ely Lake	**−.328**	**.036**	.272	.085
Hell's Kitchen Lake	**−.403**	**<.001**	−.086	.464
Little Pine Lake	**−.354**	**.043**	.025	.892
Ruby Lake	−.149	.387	.182	.288
Rutz Lake	−.090	.689	−.098	.664

[a] Significant correlations at $\alpha = .05$ are in boldface.

Because the different pollen records had differing sampling intervals, the sampling interval had to be standardized before these records could be compared statistically. The mesic indices were treated with a 42 smoothing algorithm, which produces a gentle smooth of sequential data (Velleman and Hoaglin 1981). Figures 187 and 188 plot, for the pollen records located west and

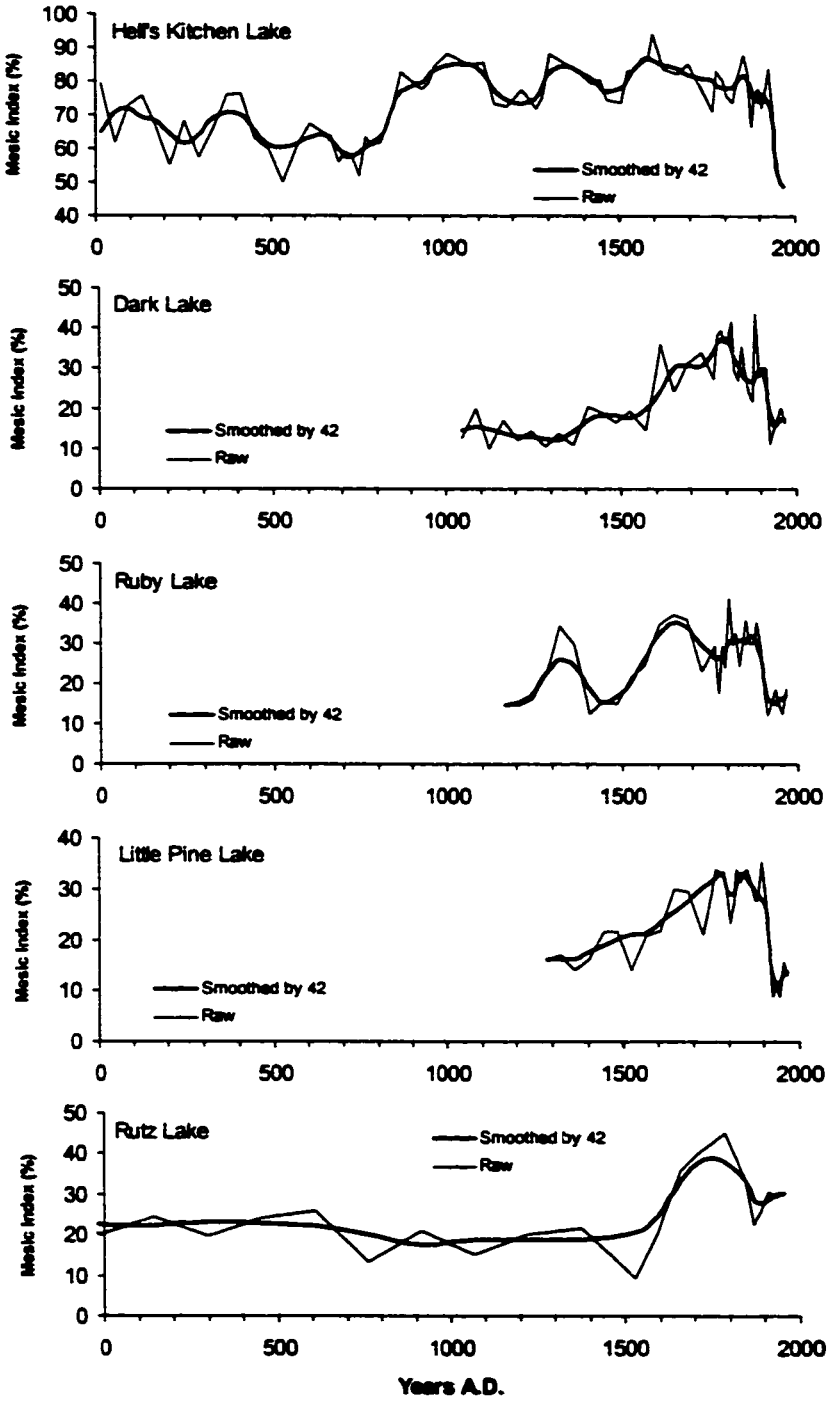


Figure 187. **Raw and 42-smoothed mesic indices for lakes located west of the Great Lakes.**

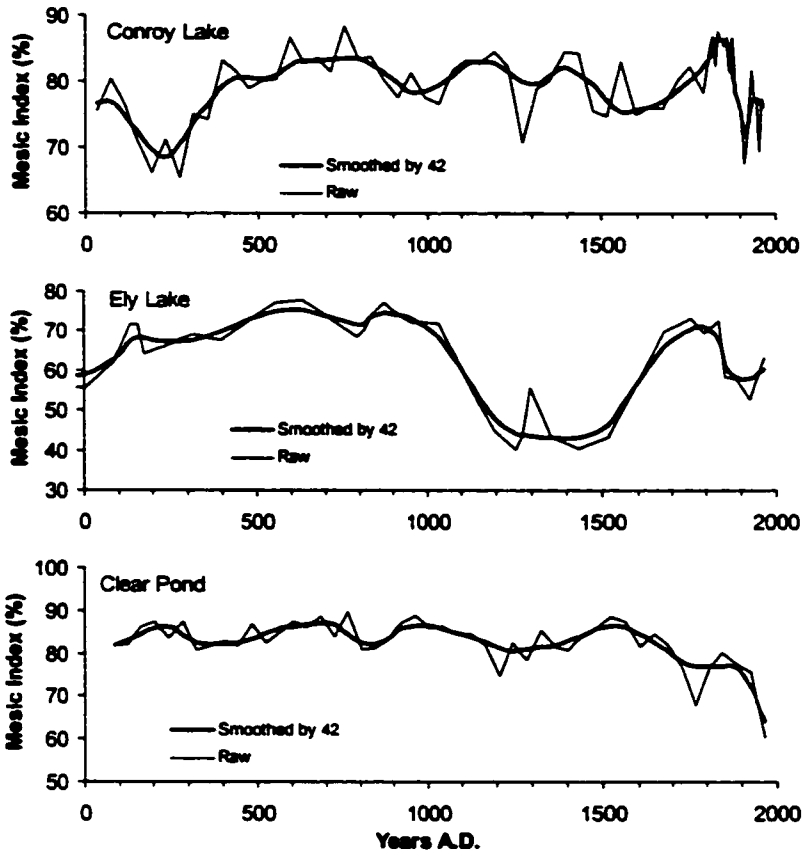


Figure 188. **Raw and 42-smoothed mesic indices for lakes and ponds located east of the Great Lakes.**

east of the Great Lakes, respectively, both the raw and the smoothed mesic index data. For every smoothed sequence, the value of the mesic index was determined at 50 year intervals. For each pollen record, the long-term mean of the mesic index was subtracted from each 50-year determination to express it as a deviation from the mean. For scaling purposes, the deviations were then divided by that mean and converted to percentages.

Figure 189 presents the mesic indices (as percent deviations from the mean) for individual lakes and ponds located west and east of the Great Lakes area, as well as the mean mesic indices for the two areas. Here, positive deviations

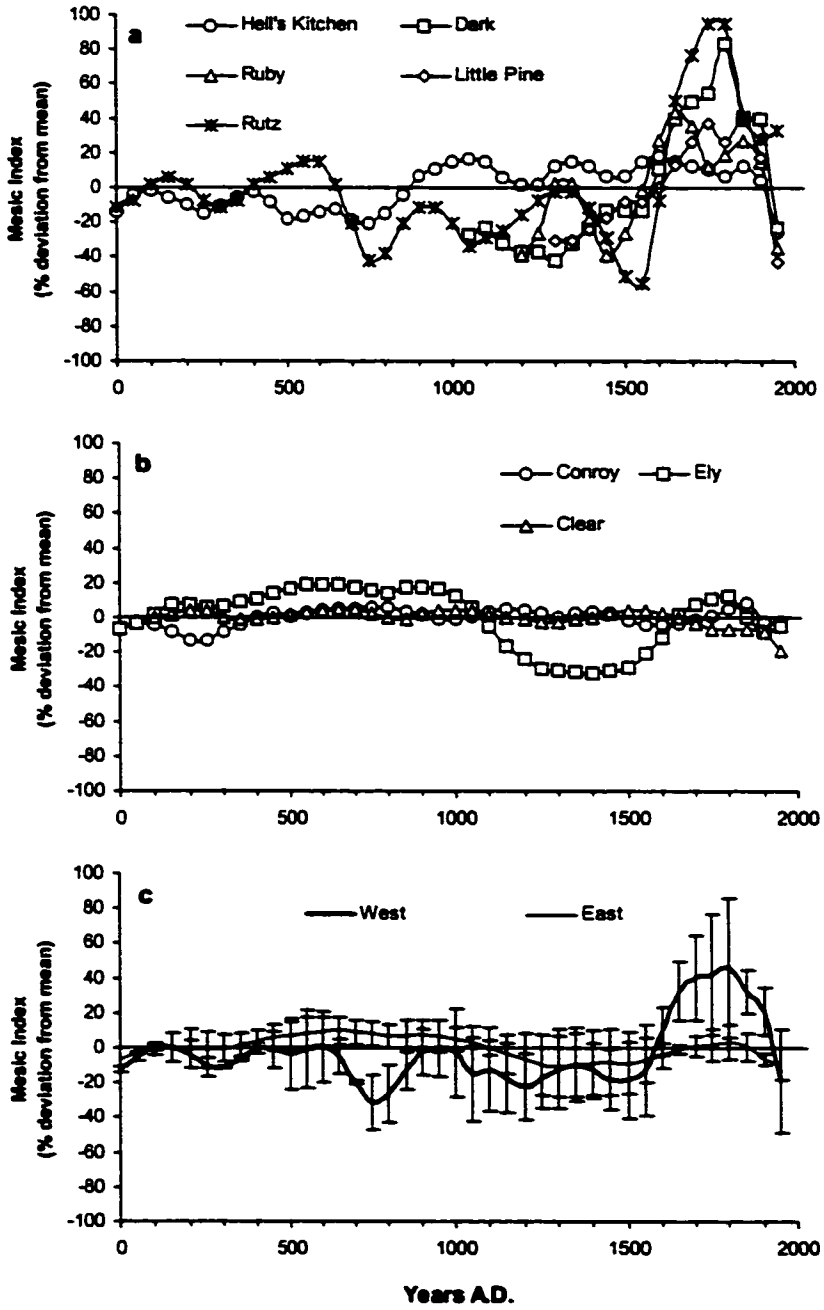


Figure 189. **Mesic indices.** Lakes and ponds (a) west and (b) east of the Great Lakes. (c) Mean (± 1 sd) mesic indices for the western and eastern pollen records.

indicate cooler and/or wetter conditions; negative deviations indicate warmer and/or drier conditions. Figures 189a and 189b illustrate how the mesic index varies both geographically and temporally. The magnitude and frequency of fluctuations in the mesic indices of the western pollen records far exceed those of the eastern records. Several of the individual sequences are significantly correlated as measured by Spearman's rho (Table 88). Of particular interest is the high degree of correlation between the Ely Lake record, in Pennsylvania, and several western records. This suggests that some climatic events may have occurred across the study region. Although spatial proximity is one factor in determining which sequences are correlated, it is clearly not the only one; other factors, such as local topography, soils, and fire regime are probably involved.

Table 88. Rank correlation coefficients (ρ) and associated significance levels (p) for the sequence of mesic indices between different pollen records. Significant correlations at $\alpha = .05$ are in boldface.

		Western Records					Eastern Records		
		HKL[a]	Dark	Ruby	LPL[b]	Rutz	Conroy	Ely	Clear
HKL[a]	ρ	1.000							
	p								
Dark	ρ	.134	1.000						
	p	.584							
Ruby	ρ	**.606**	**.678**	1.000					
	p	**.013**	**.004**						
LPL[b]	ρ	.016	**.924**	**.696**	1.000				
	p	.957	**<.001**	**.006**					
Rutz	ρ	-.089	**.532**	**.668**	**.585**	1.000			
	p	.584	**.019**	**.005**	**.028**				
Conroy	ρ	-.095	-.201	-.222	.164	-.149	1.000		
	p	.567	.410	.408	.576	.365			
Ely	ρ	**-.484**	**.678**	**.604**	**.756**	.197	.217	1.000	
	p	**.002**	**.001**	**.013**	**.002**	.223	.184		
Clear	ρ	-.093	-.263	-.221	-.266	**-.518**	-.055	**.323**	1.000
	p	.580	.277	.411	.358	**.001**	.745	**.048**	

[a] HKL = Hell's Kitchen Lake
[b] LPL = Little Pine Lake

To explore the significance of temporal variation in the mesic index, the 2000 years were subdivided into four blocks of five hundred years each. Visually, there appear to be differences in the mean value and variance of the mesic indices among those divisions. Using a Kruskal-Wallis test, both the western and eastern mesic indices (Figure 189c) were found to differ among those arbitrary time periods (West: $\chi^2 = 24.217$, $p < .001$; East: $\chi^2 = 9.935$, $p = .019$), and a Levene's test for homogeneity of variance found the variances to differ significantly, as well (West: $F = 15.920$, $p < .001$; East: $F = 8.170$, $p < .001$). The same conclusions result when values of the mesic index are compared among culture historical time periods (i.e., Middle Woodland, Late Woodland, Late Prehistoric, and Protohistoric/Historic). Although Mann-Whitney ($U = 502.000$; $p = .004$), Kolmogorov-Smirnov ($Z = 2.012$; $p = .001$) and Wald-Wolfowitz Runs (minimum runs: $Z = -4.501$, $p < .001$; maximum runs: $Z = -3.150$, $p = .001$) tests all indicate the two samples (western and eastern mesic index sequences) come from populations with different distributions, Figure 189c shows that the standard deviations of the mesic indices overlap significantly between the western and eastern records over most of the sequence.

The mean mesic indices for the western and eastern records (Figure 189c) show substantial temporal variation, however large standard deviations reflecting spatial variation tend to "flatten" many potential temporal patterns. This is especially true of the western sequence, the mean and standard deviation of which both vary tremendously. Still, there are some episodes of synchronous changes and divergences between the two records which are worth noting. There appear to be increases in both mean mesic indices beginning at roughly A.D. 300 and decreases at roughly A.D. 600. The latter decrease is more pronounced in the western records, resulting in a significant divergence between the two sequences until ca. A.D. 850. At roughly A.D. 1000, both sequences appear to decrease, although there is considerable variation among individual records; this event would be roughly coincident with the timing of the Medieval Warm Period. At A.D. 1550,

the indices increase; again, the change in the western sequence is more pronounced than in the eastern one, resulting in a divergence between them. The increase is consistent with climatic changes associated with the Little Ice Age, as is its decrease ca. A.D. 1800.

SUMMER TEMPERATURE

Gajewski (1988) used multiple regression to establish calibration functions for mean summer (JJA) temperature (°C) and annual precipitation (mm) from modern pollen abundances and climate. Those equations were applied to pollen cores from seven of the cores in Table 85 (excluding Black Pond, Rutz Lake and Ely Lake) plus Lake of the Clouds to reconstruct the history of summer temperature and annual precipitation (http://www.ngdc.noaa.gov/paleo/). For each mean summer temperature record, I used a 42 smoothing algorithm (shown relative to the raw data in Figures 190 and 191), determined the values at 50-year intervals, and expressed these values as percent deviations from the long-term means of each site (Figures 192a and 192b).

In Figure 192, positive deviations indicate warmer than average temperatures and negative deviations indicate cooler than average conditions. The reconstructed mean summer temperature record shows generally decreasing temperatures through time, particularly for the eastern sites. Although the western records clearly document a late warming trend, especially since the early 1900s, that is not apparent among the eastern records over that part of the sequence. As for the mesic index, when the individual sequences are compared, several are found to correlate positively (Table 89); again, while geographic proximity is often important in determining which sites will correlate, it is apparently not always the most important factor.

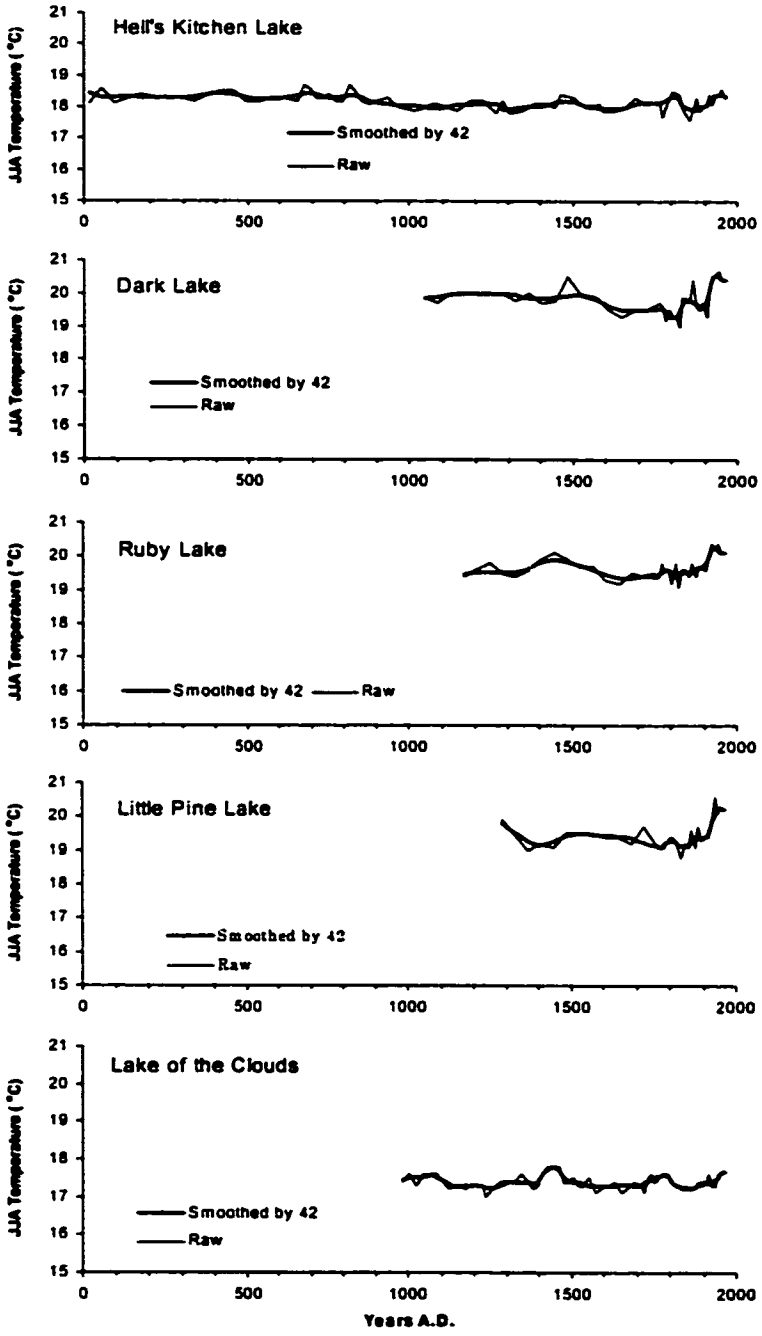


Figure 190. Raw and 42-smoothed summer temperatures for lakes located west of the Great Lakes.

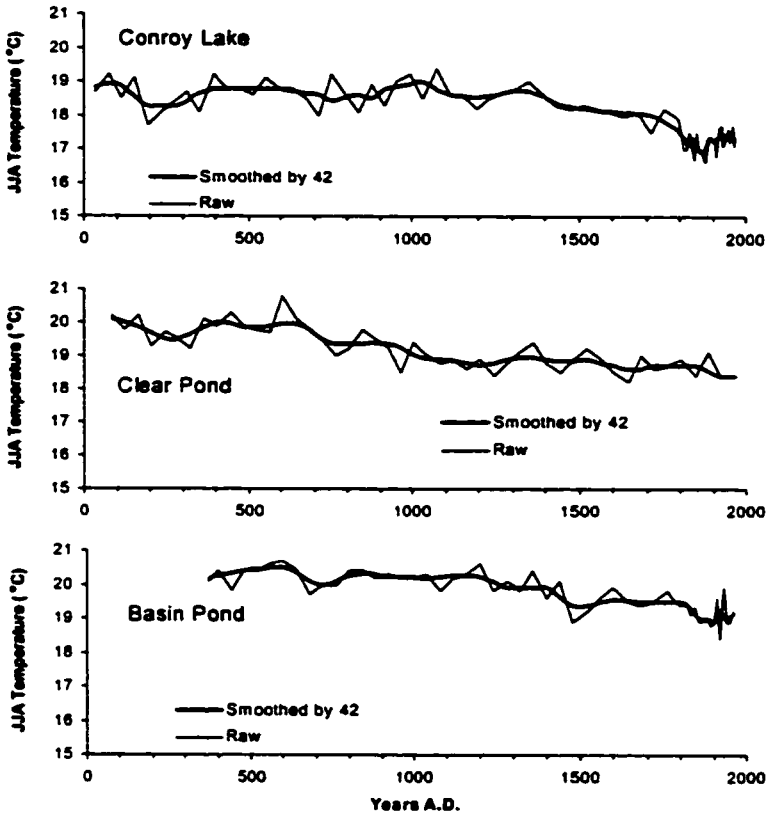


Figure 191. **Raw and 42-smoothed summer temperatures for lakes and ponds east of the Great Lakes.**

When the mean summer temperature records for the eastern and western pollen sites are examined, they are found to vary significantly through time. Kruskal-Wallis tests comparing temperatures for the eastern and western temperature records across both arbitrary 500-year blocks of time and culture historical periods indicated statistically significant differences. Relatively warmer summer temperatures are suggested in the eastern records for the periods A.D. 1 – A.D. 200, A.D 400 – 700 and A.D. 900 – 1100; in the western records, the periods A.D. 400 – 500, A.D. 600 – 700, A.D. 800 – 900, A.D. 1400 – 1500 and post-A.D. 1900, have warmer summers than usual. The subtle warm episode in the eastern record at ca. A.D. 900 – 1100 is roughly coincident with the Medieval Warm Period

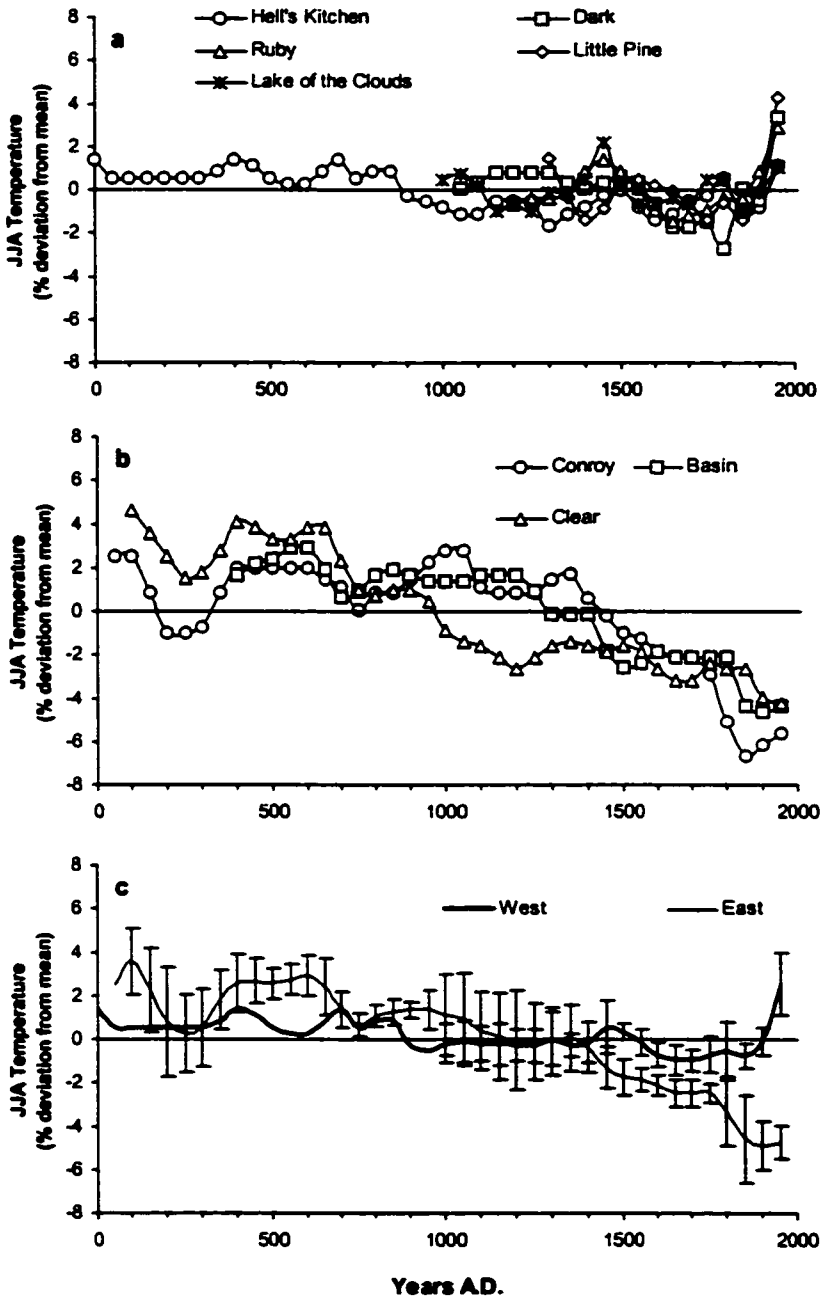


Figure 192. **Summer temperature.** Lakes and ponds from (a) west and (b) east of the Great Lakes. (c) Mean (± 1 sd) temperatures for the western and eastern pollen records.

and the fairly abrupt drop in summer temperature ca. A.D. 1450 probably corresponds to the onset of the Little Ice Age. The Medieval Warm Period is not well-recorded in the western sites, but a drop in summer temperature after A.D. 1500 may signal the Little Ice Age there. That these past climatic events could have been variably expressed geographically is consistent with current understanding of them.

Table 89. Rank correlation coefficients (ρ) and associated significance levels (p) for the sequence of reconstructed summer temperatures between different pollen records. Significant correlations at $\alpha = .05$ are in boldface

		Western Records					Eastern Records		
		HKL[a]	Dark	Ruby	LPL[b]	LOC[c]	Conroy	Clear	Basin
HKL[a]	ρ	1.000							
	p								
Dark	ρ	.127	1.000						
	p	.603							
Ruby	ρ	.355	**.522**	1.000					
	p	.177	**.038**						
LPL[b]	ρ	-.089	.515	.187	1.000				
	p	.761	.059	.523					
LOC[c]	ρ	.306	-.094	**.542**	-.101	1.000			
	p	.190	.702	**.030**	.731				
Conroy	ρ	.125	.455	.035	.126	.094	1.000		
	p	.449	.050	.898	.667	.692			
Clear	ρ	**.591**	.273	.252	-.123	.272	**.680**	1.000	
	p	**<.001**	.257	.346	.675	.245	**<.001**		
Basin	ρ	**.374**	.322	-.268	-.169	-.060	**.783**	**.785**	1.000
	p	**.035**	.179	.316	.563	.801	**<.001**	**<.001**	

[a] HKL = Hell's Kitchen Lake
[b] LPL = Little Pine Lake
[c] LOC = Lake of the Clouds

Tests which compare the underlying distributions of the populations from which the eastern and western temperature records were drawn give somewhat mixed results. A Mann-Whitney test indicates they do not differ significantly at $\alpha = .05$ ($U = 693.000$, $p = .393$), while the Kolmogorov-Smirnov ($Z =$

1.382; $p = .044$) and Wald-Wolfowitz Runs ($Z = -3.963$; $p < .001$) tests indicate that they do. Certainly, there are times when the two sequences are virtually identical, however over most of the 2000 years considered here, they appear to differ.

ANNUAL PRECIPITATION

Gajewski's (1988) annual precipitation estimates are shown in Figures 193 and 194. These figures plot both the raw estimates and the 42-smoothed sequences. All of the precipitation records are also plotted in Figures 195a and 195b as percent deviations from the mean. Positive deviations reflect greater than average annual precipitation levels, and negative deviations indicate relatively dry years. A general trend of increasing precipitation through time is apparent, with a rapid decrease since the early- to mid-1800s. As shown in Table 90, several of the individual sequences are significantly correlated. Some correlations are among geographically proximate sites, while others are among distant sites. Although one might attribute this pattern to the localized nature of precipitation, the same kinds of correlational patterns among sites were exhibited by the temperature and mesic index data, as well.

Variation in mean annual precipitation for the western and eastern groups (Figure 195c) is particularly striking in its temporal distribution. When the mean annual precipitation for western and eastern groups of pollen records is compared across 500-year time intervals and culture historical time periods, the results indicate statistically significant differences for both aggregations. Levene's tests conclude that the variances do not differ across time periods, however. For both the eastern and western sequences, annual precipitation is lower prior to A.D. 1000 than it is after A.D. 1000. Early in the sequence, there appear to be periods of increased moisture dating ca. A.D. 300 – 500 and after A.D. 650 in the west and A.D. 400 – 600 in the east. A second, longer episode of relatively high precipitation occurs in both areas, more strongly pronounced in the western than the eastern

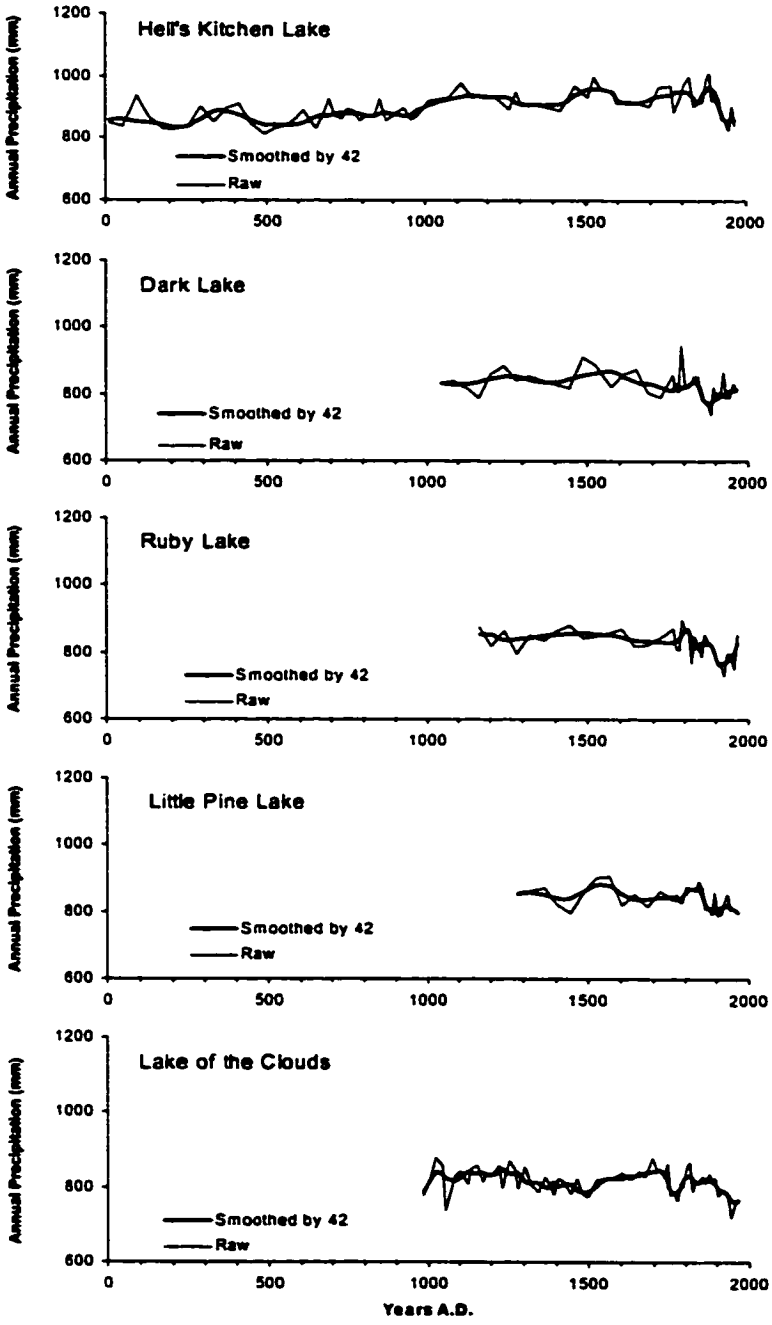


Figure 193. Raw and 42-smoothed annual precipitation for lakes located west of the Great Lakes.

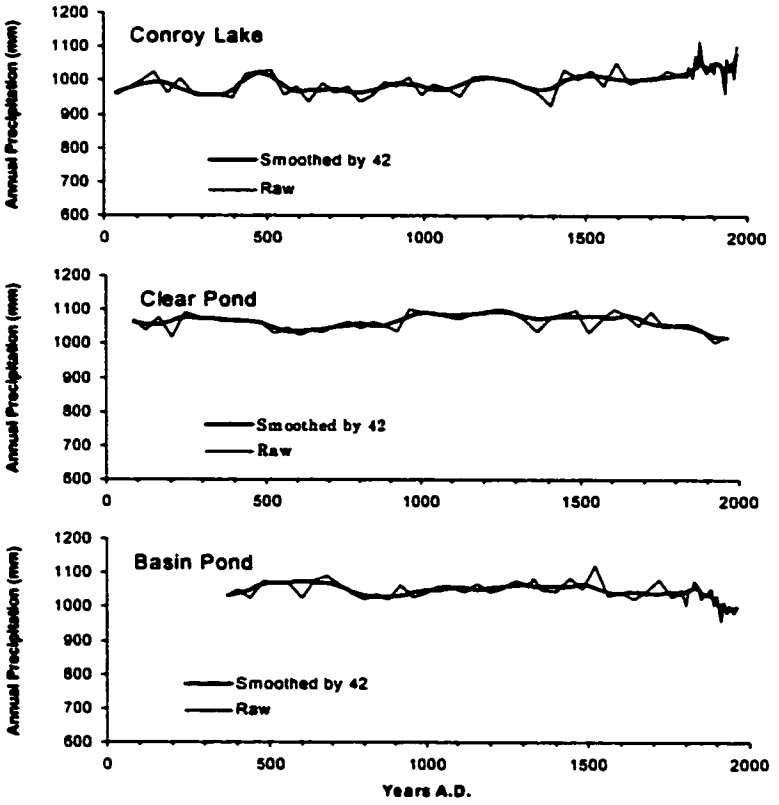


Figure 194. **Raw and 42-smoothed annual precipitation for lakes and ponds located east of the Great Lakes.**

record, from about A.D. 1000 – 1800. The conclusions of tests to evaluate whether the eastern and western samples come from populations with the same distribution are pretty conclusive that they do (U = 36.000, p = .315; Z = .894, p = .400; Z: minimum runs = -1.608, p = .051; Z: maximum runs = .000, p = .586). Thus, apparent geographic differences in annual precipitation between the two sequences (e.g., prior to A.D. 1000, the eastern and western groups have distinctly different distributions, whereas after A.D. 1000, the eastern and western groups track each other quite closely) are not statistically significant.

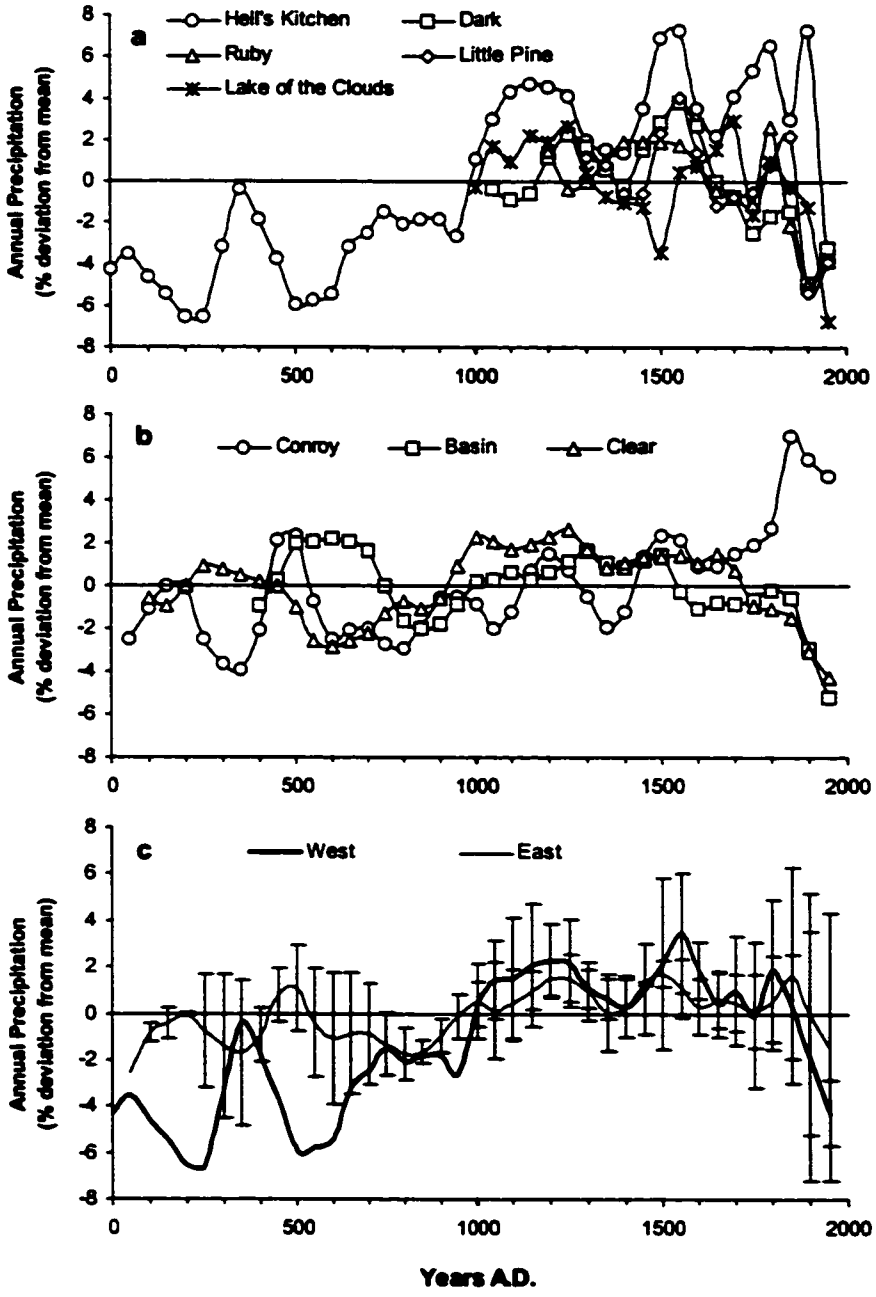


Figure 195. **Annual precipitation.** Lakes and ponds (a) west and (b) east of the Great Lakes. (c) Mean (± 1 sd) precipitation for the western and eastern pollen records.

Table 90. Rank correlation coefficients (ρ) and associated significance levels (p) for the sequence of reconstructed annual precipitation between different pollen records. Significant correlations at $\alpha = .05$ are in boldface.

		Western Records					Eastern Records		
		HKL[a]	Dark	Ruby	LPL[b]	LOC[c]	Conroy	Clear	Basin
HKL[a]	ρ	1.000							
	p								
Dark	ρ	.012	1.000						
	p	.960							
Ruby	ρ	.140	**.554**	1.000					
	p	.606	**.026**						
LPL[b]	ρ	.264	**.694**	.453	1.000				
	p	.362	**.006**	.104					
LOC[c]	ρ	.121	.154	.093	.111	1.000			
	p	.612	.530	.732	.704				
Conroy	ρ	**.439**	-.327	-.320	-.015	-.333	1.000		
	p	**.005**	.172	.227	.958	.151			
Clear	ρ	**.434**	**.590**	.421	.382	**.559**	-.006	1.000	
	p	**.007**	**.008**	.105	.178	**.010**	.970		
Basin	ρ	-.184	**.558**	**.633**	.522	.031	-.210	.121	1.000
	p	.313	**.013**	**.008**	.056	.896	.248	.508	

[a] HKL = Hell's Kitchen Lake
[b] LPL = Little Pine Lake
[c] LOC = Lake of the Clouds

IMPLICATIONS

The accuracy of statements about climatic change over the past 2000 years using the mesic index rests on the selection of appropriate plant taxa for that task. If the plants which compose the mesic index did not respond to climatic stimuli or did not respond in expected ways, then variation in that index might reflect something other than climatic change. Spearman's rank correlation coefficients were used to examine the relationship between the mesic index and reconstructed summer temperature and annual precipitation for six pollen records where those data are available. The mesic index is expected to have a negative

relationship with temperature and a positive one with precipitation. The results (Table 91) suggest that on a site-by-site basis, the mesic index primarily responds to summer temperature and that its relationship with annual precipitation is variable and generally insignificant.

Table 91. Spearman's rank correlation coefficients (ρ) and significance levels (p) indicating the relationship between the mesic index and reconstructed JJA temperature and annual precipitation. Significant correlations at $\alpha = .05$ are in boldface.

		Precipitation		Temperature	
	n	ρ	p	ρ	p
Hell's Kitchen Lake	73	**.688**	**<.001**	**-.834**	**<.001**
Dark Lake	39	-.421	.073	**-.832**	**<.001**
Ruby Lake	36	-.351	.183	**-.655**	**.006**
Little Pine Lake	33	.060	.839	**-.548**	**.043**
Conroy Lake	68	-.045	.786	.118	.476
Clear Pond	48	.119	.476	**.475**	**.003**

Of course, these parameters are not independent. In addition, comparisons in Table 91 assume that the values for reconstructed summer temperature and annual precipitation are accurate, that mean summer temperature and annual precipitation are appropriate variables for comparison with the mesic index, and that the relationship between mesic index and temperature and/or precipitation remained the same over the entire sequence. With regards to the first assumption, Gajewski (1988) indicates that the explanatory power (adjusted R^2) of the regression equations used to estimate these parameters varies from roughly 15% for annual precipitation and 65% for JJA temperature among the eastern sites, to 81% for JJA temperature among the western sites. Given this information, that the behavior of the mesic index is not consonant with expectations based on reconstructed precipitation and temperature, particularly for the eastern sites, is

not condemning. With regards to the second assumption, that JJA temperature and annual precipitation are relevant to the pollen abundances of mesic taxa, they certainly may be important variables; other variables such as summer precipitation or fire frequency may be equally important. Finally, the third assumption, that the relationship between mesic index and temperature and/or precipitation remained constant through time, requires some evaluation.

The nature of the relationships among the three variables can be evaluated by generating multiple regression equations for different blocks of time. If the relationships do not vary, then similar equations should result. Table 92 presents the solutions of multiple regressions for the eastern and western mesic indices across four 500-year blocks of time. Independent variables included temperature and precipitation for the eastern and western groups of pollen records. The models were allowed to incorporate geographically disparate variables (e.g., equations for the western mesic index may include temperature and precipitation from the eastern records) because correlations among those variables frequently crossed the region, suggesting some common climatic patterns. In only one case (eastern mesic index for the period A.D. 1000 – 1450) did the regression fail to produce a statistically significant equation. Various combinations of precipitation and temperature are found to account for differing proportions, ranging from 50 – 97%, of the variation in the mesic index.

It is quite clear that, over time, the relationship of the mesic index with summer temperature and annual precipitation varies. Thus, high values of the mesic index do not necessarily reflect cool and wet conditions. This was confirmed visually by plotting those variables against each other in Figure 196. In the west, high values of the mesic index in the early part of the sequence appear to reflect relatively warmer and wetter conditions; in the middle of the sequence, they are more consistent with cooler and drier conditions; and, in the more recent portion of the sequence, they reflect cooler, and perhaps wetter, conditions. In the east, high

values of the mesic index reflect relatively warmer and wetter conditions during the early part of the sequence; in the middle of the sequence, they may reflect cooler and drier conditions; and, in the more recent part of the sequence they may be driven by cooler and wetter conditions.

Table 92. Statistics for stepwise solutions to multiple regression models explaining variance in the eastern (E) and western (W) mesic indices through time.

Time Period	Index	R^{2a}	Variables	Standardized *B*	*t*	Significance
A.D. 1 – 450	W	.751	constant		-9.136	<.001
			Temp (E)	.940	5.012	.002
	E	.805	constant		-8.567	<.001
			Temp (W)	.611	3.456	.014
			Temp (E)	.464	2.622	.039
A.D. 450 – 950	W	.507	constant		-.971	.360
			Temp (W)	-.749	-3.200	.013
	E	.600	constant		3.243	.012
			Precip (E)	-.803	-3.807	.005
A.D. 1000 – 1450	W	.633	constant		-3.513	.008
			Temp (E)	.633	4.061	.004
	E	—	—	—	—	—
A.D. 1500 – 1950	W	.966	constant		-2.490	.042
			Temp (W)	-1.039	-15.969	<.001
			Temp (E)	-.381	-5.855	.001
	E	.957	constant		-10.223	<.001
			Precip (W)	.602	7.371	<.001
			Temp (W)	-.348	-4.464	.004
			Precip (E)	.322	4.328	.005

[a] R^2 (adjusted)

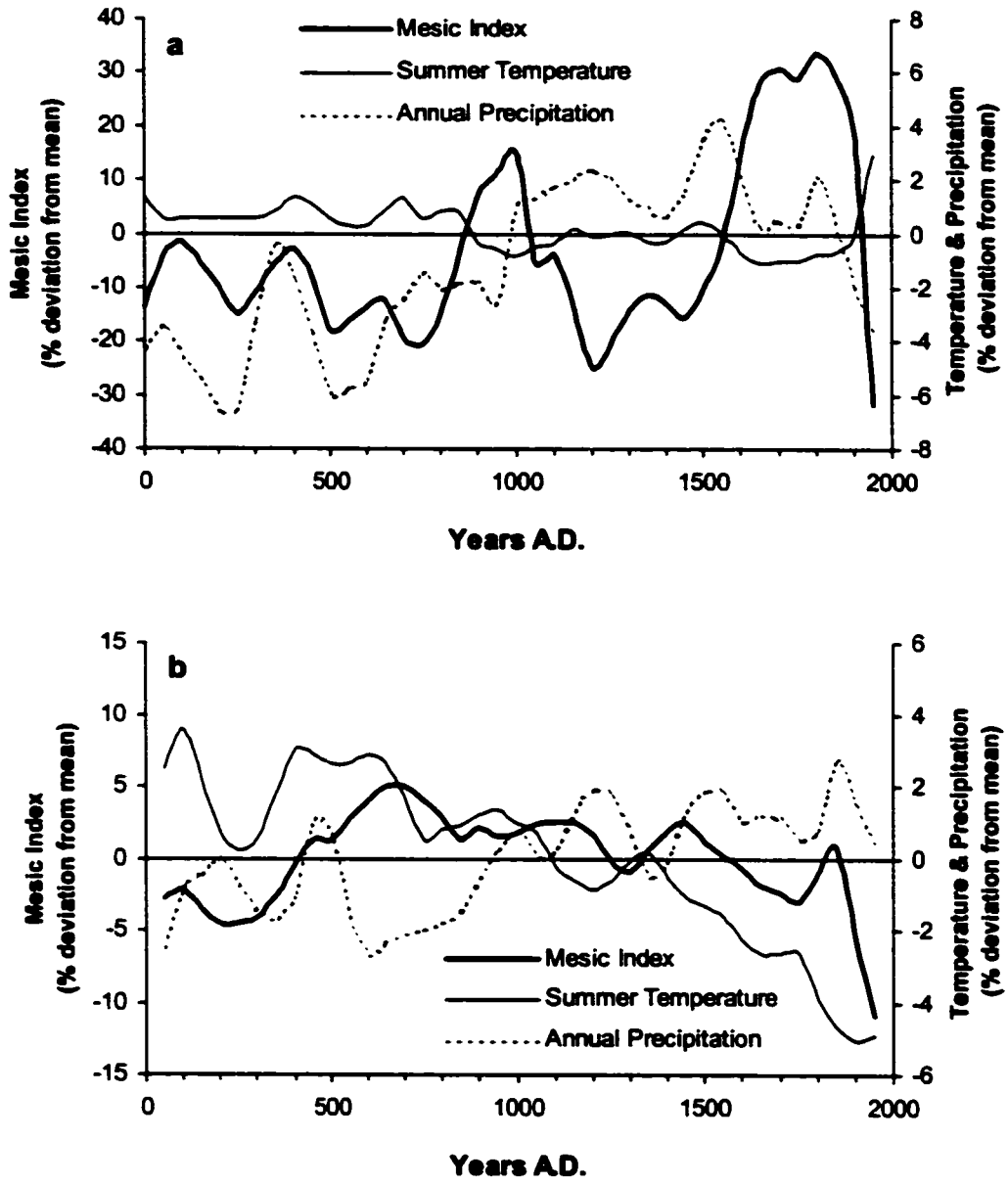


Figure 196. **Climatic parameters derived from pollen records.** (a) West and (b) east of the Great Lakes region.

Despite finding that variation in the mesic index is only partially and variably accounted for by reconstructed summer temperature and annual precipitation, the mesic index remains a valuable tool. In particular, rapid changes in the index signal changes in climatic conditions outside of summer temperature

and annual precipitation. Further research may reveal what those other variables are and what relevance they hold for human subsistence in the region.

Temporal variation in these parameters is summarized in Figure 197. Although the underlying data showed substantial geographic variation among pollen sequences that might in some situations make using averages unwarranted, at two standard deviations they overlapped so completely that averaging them here appears justified. In addition, because my interest is in developing a *regional* sequence of climate that will encompass the study region, averaging will allow me to identify climatic episodes of similar direction and timing (they should be additive and appear as distinct peaks or valleys, while those of opposite direction or out of sync should be subtractive and appear flat). In this graph, positive deviations from the summer temperature mean reflect warmer than average conditions and positive deviations from the annual precipitation mean indicate wetter than average conditions. As already shown, the mesic index is related variably to these parameters.

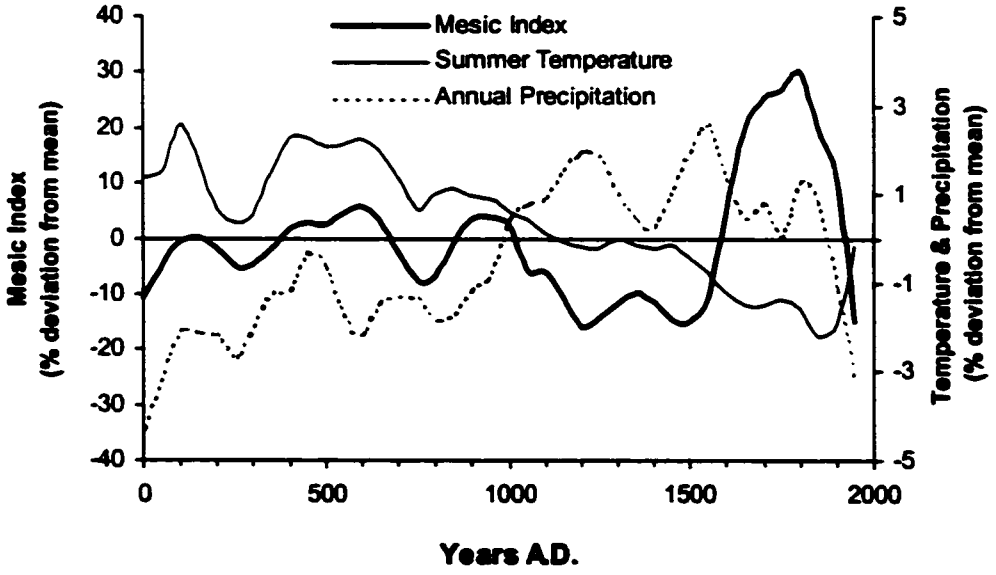


Figure 197. **Mesic index, summer temperature and annual precipitation.**

Based on Figure 197, some general statements about prehistoric climatic change over the relevant time period, A.D. 400 – 1650, can be made. In particular, note that just prior to A.D. 400, rapid increases in the mesic index, summer temperature and annual precipitation are documented. Annual precipitation apparently began decreasing ca. A.D. 500, but summer temperatures and the mesic index remained high until roughly A.D. 700. At around A.D. 800, summer temperature and the mesic index, followed shortly by annual precipitation, began to increase again. Even as summer temperature and the mesic index decreased around A.D. 1000, annual precipitation continued to increase until roughly A.D. 1200. Interestingly, as annual precipitation began to decrease and summer temperature remained about the same, the mesic index increased. As the mesic index began decreasing in about A.D. 1350, annual precipitation began to increase again. Finally around A.D. 1500, with temperature continuing to decrease, and precipitation decreasing as well, the mesic index increased and stayed high until roughly A.D. 1800. This episode corresponds with the previously identified Little Ice Age, the end of which is marked by rapid decreases in the mesic index and annual precipitation and by an increase in summer temperature.

BEACH RIDGES AND DUNES

The chronology of beach ridge and dune formation on the Great Lakes shores provides another source of information about past climatic change. Beach ridges and dunes are products of short-term fluctuations in lake water level. In the absence of major structural alterations to the outlet, lake levels are determined by precipitation and temperature over the drainage basin. Thus beach ridges and dunes reflect climatic conditions averaged over a larger area than do pollen records. Around the upper Great Lakes, several complexes of permanent beach ridges and dunes were formed as lake levels dropped through the Holocene and were preserved as shorelines rose due to isostatic rebound (Larsen 1994). Thus, by identifying relict

beach ridges or dunes and dating their formation, geologists can establish past climatic conditions in the Great Lakes area.

The formation of shoreline beach ridges begins with the deposition of offshore beach bars during times of high water level (Olson 1958). Wave action creates these sand bars as a series of (typically) three submerged ridges running parallel with the shore, each having a landward depression. Receding lake waters expose the near-shore ridge, and breaking waves and winds add additional material to it, building it up. If lake levels remain low long enough for the ridge to build sufficiently (on the order of 7 – 10 years) and if terrestrial vegetation can colonize the ridge, it may resist erosion and become a permanent lakeshore feature (Olson 1958). The depressions, or swales, between ridges provide habitat for wetland vegetation.

If lake levels increase again and erosion occurs, the erosion conforms to the structure of the shoreline and ridge complexes are not removed entirely nor uniformly (Fraser et al. 1990). Some portions of the ridges will remain; later deposited ridges will be oriented differently relative to the older ridge complexes due to changes in the shoreline. Beach ridges are not easily erased and thus potentially provide a long-term record of lake level fluctuations. Ridge age is usually determined by radiocarbon dating basal peat deposits from adjacent swales. Former lake levels are best estimated by coring the ridges and swales and analyzing the sedimentological characteristics of the internal structure of these features (Thompson 1992). The base of the underlying foreshore stratum approximates the (high) lake level when the beach was formed; its thickness informs on wave energy and sediment supply.

Lakeshore dunes are low lake level phenomena (Olson 1958). Plants colonizing the expanded beach area trap eolian sands, forming ridges running parallel to the lake. The dunes may become sufficiently large to resist erosion should lake levels rise, thus becoming permanent features of the shoreline. Perched

dune fields, in contrast, are not shoreline features. They form in elevated situations through the eolian deposition of sediments derived from lake-facing bluffs (Anderton and Loope 1995). During times of low water level, bluff faces are stable and little material is available for eolian transport; the dunes experience soil development and vegetation colonization during these times. When lake waters rise and begin to erode the bluff faces, slope failure exposes fresh surfaces, thus providing an abundant sediment supply for eolian transport to the perched dunes, burying soils and vegetation alike. For both lakeshore and perched dunes, the chronology of dune formation is usually established by determining the age of paleosols or vegetation covered by episodes of eolian deposition.

Determining the age of beach ridge and dune features is not at all straightforward, however (cf. Bishop 1990; Hansel et al. 1990; Larsen 1994; Thompson 1992). Dendrochronological assessments of trees on or between ridges and radiocarbon determinations of basal peat deposits from interridge wetlands provide minimum ages that are not directly linked to the age of the features. Although ridge age should increase with distance from the modern shoreline, in some cases the ages of basal peat from the interridge swales cluster, reflecting environmental conditions in the swales as they relate to wetland development more than reflecting the age of the adjacent beach ridges (Hansel et al. 1990). Additionally, some (Hansel et al. 1990; Petty et al. 1996) have noted that there may be a significant time lag between formation of a ridge and the accumulation of organic materials in its associated swale. Interpreting radiocarbon determinations of paleosols underlying dunes can be complicated similarly by variation in organic material accumulation and residence times; using plant macrofossils to estimate the timing of dune formation is dependent on vegetation colonization rates.

Several studies of past lake level fluctuations have been conducted using beach ridge and dune features along the shores of the Upper Great Lakes (Figure 198, Table 93). The results of these studies fail to produce a coherent

picture of lake level change through time. While there are overlaps among them in the timing of lake level fluctuations, different researchers (Delcourt et al. 1996; Fraser et al. 1990; Petty et al. 1996; Thompson 1992) have established different periodicities for lake level fluctuations. These chronological differences are not patterned as might be expected if geographical variation (i.e., if lake level events occurred at different times or rates across the drainage basin) was an important variable.

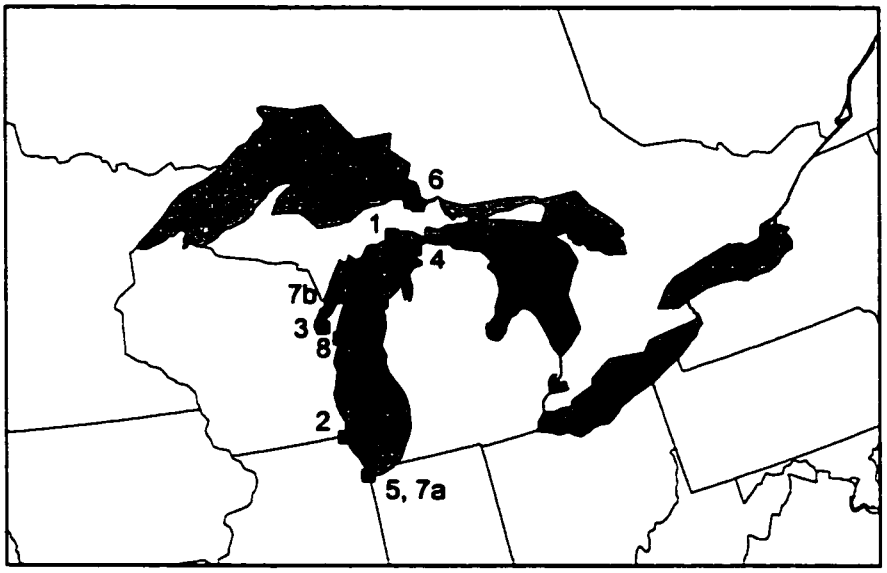


Figure 198. **Location of Great Lakes beach ridge and dune features.** Numbers indicate sites listed in Table 93.

There are reasons, however, why results of these studies might not be directly comparable: (1) they rely on different kinds of features to establish lake level conditions; (2) they use different aspects of the features (e.g., frequency of ridge formation, ridge height, height of basal foreshore deposits, or vegetational history of swale deposits) to establish the direction and magnitude of water fluctuations; (3) local conditions (e.g., topography, wind direction, and proximity to sediment source) at each location probably cause the same water level events to be recorded with different sensitivities; and (4) error associated with establishing the

lake level chronologies is not well-controlled. Resolution of these problems is not possible with the published data and is clearly beyond the scope of this project; instead, I emphasize the broad trends in past water level fluctuations shown by these studies.

Table 93. Great Lakes beach ridge and dune sites shown in Figure 198.

Map #	Location	References
1	n shore, Lake Michigan	Delcourt et al. 1996; Petty et al. 1996
2	sw shore, Lake Michigan	Fraser et al. 1990; Larsen 1985
3	Baileys Harbor, WI	Johnson et al. 1990
4	Wilderness State Park, MI	Lichter 1995
5	Toleston Beach, IN and IL	Thompson 1992
6	Grand Sable Dunes, MI	Anderton and Loope 1995
7a-c	a, Gary Airport, IN; b, Sturgeon Bay, WI; c, Whitefish Point, MI	Larsen 1994
8	Two Rivers, WI	Dott and Mickelson 1995

Researchers differ in the climatic conclusions they draw from the beach ridge data. Recall that the initial formation of a ridge feature happens under conditions of high lake level, yet its preservation depends upon its colonization by terrestrial vegetation; the latter process requires low lake levels. As a consequence, some (e.g., Delcourt et al. 1996; Fraser et al. 1990) emphasize the climatic conditions necessary for the initial formation of ridges and conclude that beach ridges are indicators of high lake levels. Others (e.g., Lichter 1995) emphasize the conditions necessary for the stabilization and preservation of ridges and conclude that beach ridges indicate generally low lake levels. Both interpretations are consistent with historic observations; beach ridges result when episodes of high lake

levels are followed by rapid decreases in water levels (Lichter 1995). A third interpretation, that beach ridges reflect times of great climatic variation, is thus also merited. The nature of correlations between beach ridges and other climatic data sets should indicate which interpretation is most likely correct.

Assuming that historically-documented relationships between lake level fluctuations and climatic conditions in the Upper Great Lakes drainage basin can be extended back over the past 2000 years, climatic conditions during high lake level events can be reconstructed. Historically, elevated lake waters correlate most strongly with higher precipitation (especially during the late spring/early summer and the winter) and less strongly with lower temperatures (especially during the early summer) (Fraser et al. 1990). If ridges are assumed to correlate with high lake water levels, then they developed during times that were wetter and perhaps cooler than intervening times.

Figure 199 plots, for each 100-year period over the past 2000 years, the number of studies with evidence for beach ridge formation. Whether or not the particular age ranges reported by the studies coincide perfectly, those time periods during which the most beach ridges are recorded appear as peaks. Four peaks are apparent: A.D. 300 – 750, A.D. 950 – 1150, A.D. 1450 – 1550, and A.D. 1600 – 1850. Please note that Figure 199 only shows the frequency with which a particular century is cited as having had beach ridges form. It does not indicate the magnitude of water level elevation, which, although desirable information, is not estimated comparably across the studies considered here and remains a contentious issue (Bishop 1990; Larsen 1985b, 1994).

Figure 199 also shows that these episodes of beach ridge formation are only roughly coincident with episodes of high lake level documented by Wolin (1996) for Lower Herring Lake, located near Lake Michigan, on the basis of paleolimnological evidence. There is a better correspondence between Great Lakes

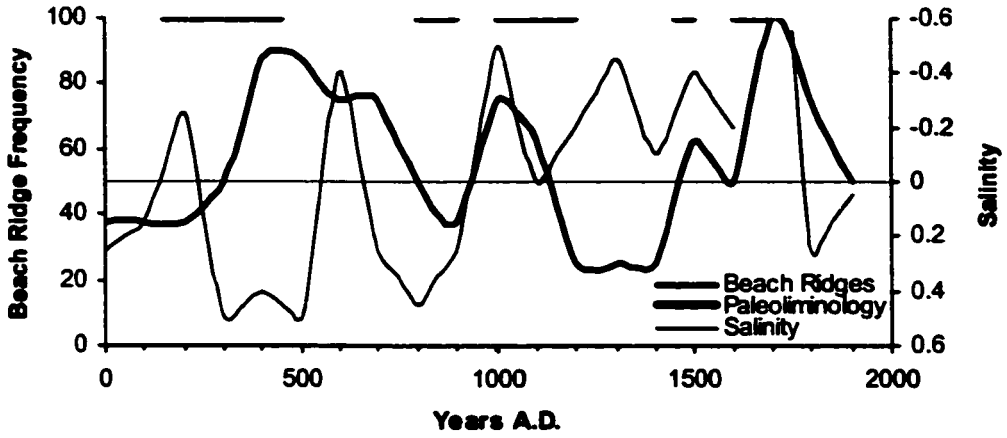


Figure 199. **Compiled frequency of beach ridge formation over the past 2000 years in the Upper Great Lakes area.** Beach ridges are compared to episodes of high lake levels recorded by paleolimnological data at Lower Herring Lake, MI (Wolin 1996) and to moisture conditions indicated by diatom-inferred salinity (presented as deviations from mean log salinity) at Moon Lake, ND (Laird et al. 1996, 1998).

beach ridge formation events and wet conditions indicated by low salinity values (negative deviations from the mean log salinity) at Moon Lake, ND; salinity values were reconstructed on the basis of changes in the composition of diatom assemblages (Laird et al. 1998, 1996). The data for the salinity curve plotted in Figure 199 were derived at 100-year intervals from a smoothed curve (Woodhouse and Overpeck 1998:Figure 11); although this estimated curve displays much less variation than the original, the major trends are reflected well. That the timing of the beach ridge and low salinity peaks appear to coincide (particularly after A.D. 900) would seem to support the notion that beach ridges may reflect high lake levels; however, even though the two variables are correlated positively, they are not correlated significantly at $\alpha = 0.05$ ($r = .184$; $p = .268$).

Figure 200 compares the beach ridge data with the pollen data from Figure 197. No attempt has been made to correct the pollen data for lag, which refers to the time between an episode of climatic change and the vegetational

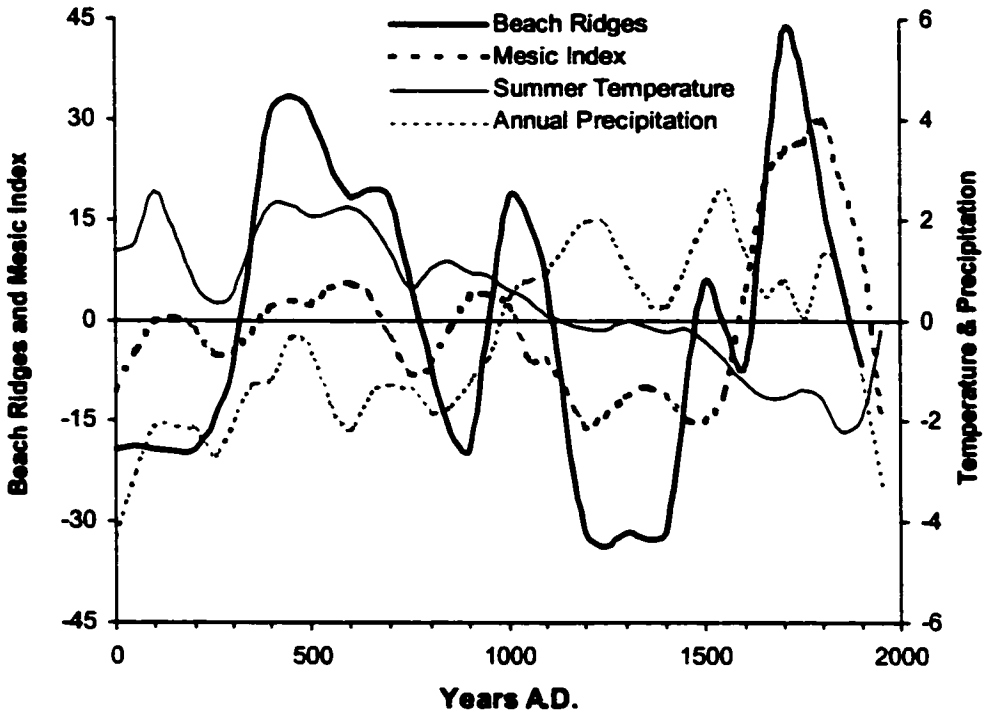


Figure 200. **Incidence of beach ridges versus mesic index, summer temperature and annual precipitation.**

response (as seen in the pollen rain) to that change. One would expect that, if beach ridges reflect primarily high lake levels, the incidence of beach ridges would correlate positively with the mesic index and annual precipitation and that it would correlate negatively with summer temperature. Visually, at least, these expectations are not always met. Multiple regression analyses were performed to determine how well patterns in the beach ridge data could be explained by climatic data from the pollen records (Table 94). Different regression models were explored, including stepwise, forward selection and backward elimination models, with the incidence of beach ridges as the dependent variable against mesic index, temperature and precipitation. All three models produced the same result that explained 54% (adjusted R^2; $F = 16.069$; $p < .001$) of the variation in the incidence of

high lake levels. All three variables were incorporated into the model, and all were positively related to the dependent variable.

That there is some correspondence among the four variables suggests that they may be tracking the same climatic episodes. Looking at Figure 200, however, it appears that relationships between the incidence of beach ridges and the other three variables vary over time. Multiple regression (Table 94) was used to examine the potentially variable nature of these relationships across 500-year

Table 94. Statistics for various solutions of the multiple regression models to explain variation in the incidence of beach ridges in terms of mesic index, summer temperature and annual precipitation.

Time Period	R^{2a}	Variables	Standardized B	*t*	Significance
A.D. 1 – 1950	.543	constant		-.698	.490
		mesic index	.840	6.867	<.001
		temperature	.612	3.910	<.001
		precipitation	.441	2.986	.005
A.D. 1 – 450	.788	constant		2.849	.022
		precipitation	.788	3.626	.007
A.D. 500 – 950	.727	constant		-1.710	.138
		mesic index	-.543	-2.242	.066
		precipitation	.440	2.318	.060
		temperature	1.222	4.909	.003
A.D. 1000 – 1450	.769	constant		-4.885	.001
		temperature	.891	5.565	.001
A.D. 1500 – 1950	.659	constant		2.928	.026
		mesic index	1.287	4.158	.006
		temperature	.867	2.802	.031

[a] R^2 (adjusted)

blocks of time. The explanatory power of the resulting equations (obtained via backward elimination) ranges from 66 – 79%; thus, a significant amount of the variation in the incidence of beach ridges over time can be accounted for by variation in mesic index, summer temperature and/or annual precipitation.

When the incidence of beach ridges is correlated positively with precipitation and the mesic index, the notion that beach ridges form under times of wet climate is seemingly supported. When beach ridges are correlated with temperature, however, the relationship is positive, suggesting beach ridges are formed during times of warmer weather. Although these two patterns of the beach ridge data might be viewed as mutually exclusive, this need not be so. One can imagine how beach ridges might have formed as unusually high lake levels receded to more "normal" levels or as "normal" lake levels receded to "low" levels; in the first instance, one might see a rough correlation with wetter, perhaps cooler, conditions and in the second, a correlation with drier, perhaps warmer, conditions. Thus, that the incidence of beach ridges shows different relationships with climatic variables through time (Table 94) does not necessarily mean that there are fatal flaws in data or logic.

From this perspective, even though the beach ridge data do not provide an easily interpreted "stand-alone" climatic scenario, they may be useful in combination with other climatic data. In Figure 200, the first peak (A.D. 300 – 750) coincides with peaks in the pollen data that indicate relatively warm and wet conditions. In contrast, the second and third peaks (A.D. 950 – 1150 and 1450 – 1550, respectively) appear as annual precipitation increases but summer temperatures decline, suggesting wetter and cooler conditions. Even though neither of these peaks is clearly associated with corresponding peaks in the pollen data, they are associated with episodes of high lake levels as shown by the other independent lake level indicators in Figure 199. Finally, the fourth peak (A.D. 1600 – 1850) corresponds to peaks in the mesic index and in the other lake level

indicators (Figure 199), suggesting generally cool, perhaps wet conditions during that time.

The third scenario, that the incidence of beach ridges and dunes might reflect a more variable climate, also remains to be addressed. Certainly, fluctuations in lake levels are required for their formation and preservation. However, the degree to which such fluctuations require a more variable climate is not clear. At any rate, this third hypothesis cannot be evaluated through comparisons with the relatively coarse pollen data available. Tree ring records, which provide information on year-to-year climatic variation, may be more useful in that regard.

TREE RING RECORDS

Although dendroclimatologists working in eastern North America have known, since the mid-1930s, that characteristics of annually-deposited tree rings can be used to reconstruct past climatic conditions (e.g., Diller 1935; Hawley 1937, 1941; Lyon 1936), archaeologists working there have generally not taken advantage of that research like they have in the Southwest (see Anderson 1994 and Anderson et al. 1995 for exceptions). One reason for this is that the bulk of the documented tree ring records in eastern North America do not extend back in time beyond about A.D. 1700, and consequently, they are of little relevance here. There are exceptions, however. Significantly longer dendroclimatological records have been developed for some areas of eastern North America, particularly in eastern Canada and in the southeastern United States. Even though these two areas are far removed from my study area, they are relied on for evidence of regional climatic change; only a few records are located near the study area in central Pennsylvania. Specifically, those dendroclimatological data were compared with the pollen and

lake-level data previously discussed, looking for evidence of climatic changes similar in terms of timing and direction.

Tree growth is a complex biological process (Fritts 1971) and there are many biological variables (e.g., tree species, tree age, nutrient availability), in addition to climatic ones (e.g., temperature, precipitation, wind speed, amount of sunshine [Stahle et al. 1991]), that can influence annual growth. Identical ring widths may result from very different growth conditions (Bradley 1985) and, consequently, identifying climatic signals from the simple measurement of tree-ring widths often requires sophisticated mathematical manipulations. First, the ring widths from each tree must be standardized to remove the effects of slowed growth as the tree aged. The calculated standardized ring width indices are then averaged for each year across several trees at a locale. The averaging process tends to improve the climatic signal (common to all trees at the locale) while reducing nonclimatic variation (varies more-or-less randomly among trees at the locale). The mean ring width indices must then be related to climatic variables. The basic strategy involves observing how the index varies with some aspect of climate (e.g., growing season temperature and/or precipitation) over some period of time when instrumental records are available. Several different statistical approaches are available for this step (Bradley 1985; Fritts 1971). The calibrations must be verified either against a part of the instrumental record not used in establishing the calibration or against another source of proxy climate data. Assuming that the results of the verification step are acceptable, the resulting equations are used to estimate climate from prehistoric ring widths and a climatic history at that locale is constructed.

Available dendroclimatological sequences (in the International Tree-Ring Data Bank [ITRDB, which is part of the World Data Center - A for Paleoclimatology, administered by the Paleoclimatology Program of NOAA; data are available at http://www.ngdc.noaa.gov/paleo/treering]) were examined with regards

to four criteria: (1) geographic proximity to the study area, (2) data format, (3) taxon, and (4) time span of sequence. In terms of geographic proximity, greatest emphasis was placed on locating tree-ring sequences nearest the study area, while recognizing that the best data are from distant areas. The locations of the selected sequences are shown in Figure 201 and they are listed in Table 95. For data format, I hoped to rely on previously established climatic estimates as much as possible. Only two such data sets were available (Figures 202 and 203). Minimally, the data had to be as standardized ring width indices. Because the statistical manipulations relating tree growth and climatic variables (even once standardized ring width

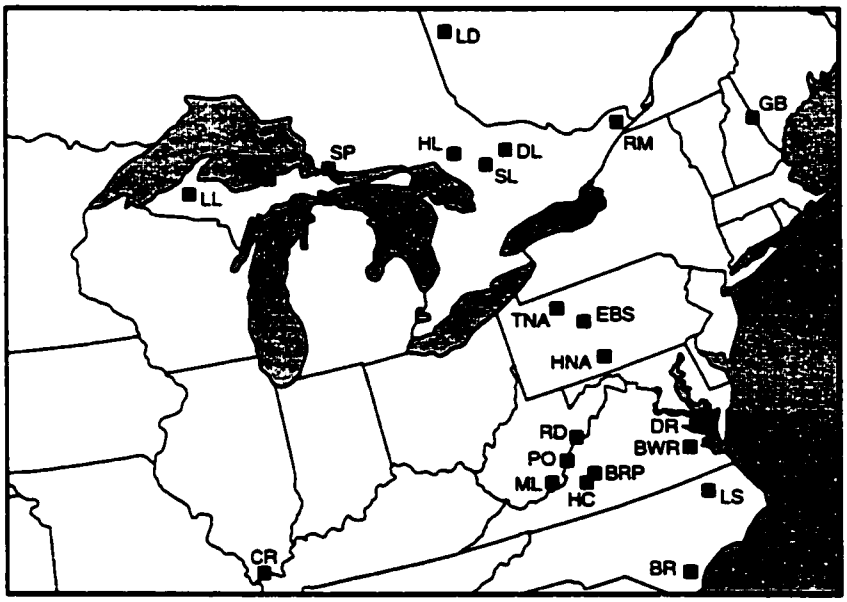


Figure 201. **Location of dendroclimatological sequences.** Key to abbreviations is in Table 95.

indices are obtained) are beyond the scope of this research, standardized ring width indices were used as gross ecological indicators of climatic conditions. All of the tree taxa used here respond in similar ways - they lay larger rings during growing seasons that are cool and wet (Archambault and Bergeron 1992; Cook 1982; Stahle et al. 1988). Finally, dendroclimatological sequences that spanned at least 350

Table 95. Dendroclimatological sequences, age span (years), data format, taxon, and contributor to the ITRDB.

Sequence	Span	Data[a]	Taxon	Contributor
Southeastern U. S.	1053	Precip.	*Taxodium distichum*	Stahle and Cleaveland 1994
Jamestown/Roanoke	800	PDSI	*Taxodium distichum*	Stahle et al. 1998
Pennsylvania sequences:				
TNA, Tionesta Nat. Area	554	SRWI	*Tsuga canadensis*	E. R. Cook
EBS, East Branch Swamp	442	SRWI	*Tsuga canadensis*	E. R. Cook
HNA, Hemlocks Nat. Area	447	SRWI	*Tsuga canadensis*	E. R. Cook
Southeastern sequences:				
CR, Cache River	518	SRWI	*Taxodium distichum*	D. W. Stahle
DR, Dragon Run	613	SRWI	*Taxodium distichum*	D. W. Stahle
HC, Hemlock Cove	452	SRWI	*Tsuga canadensis*	E. R. Cook
BWR, Blackwater River	1054	SRWI	*Taxodium distichum*	D. W. Stahle
LS, Lassiter Swamp	461	SRWI	*Taxodium distichum*	D. W. Stahle
BR, Black River	1621	SRWI	*Taxodium distichum*	D. W. Stahle
BR, Black River	1614	PDSI	*Taxodium distichum*	Stahle et al. 1988
RD, Ramsey's Draft	387	SRWI	*Tsuga canadensis*	E. R. Cook
PO, Patty's Oaks	416	SRWI	*Quercus alba*	E. R. Cook
ML, Mountain Lake	432	SRWI	*Quercus alba*	E. R. Cook
BRP, Blue Ridge Parkway	396	SRWI	*Quercus prinus*	E. R. Cook
Northern sequences:				
LL, Loon Lake	414	SRWI	*Tsuga canadensis*	E. R. Cook
PIR, Presque Isle River	540	SRWI	*Tsuga canadensis*	E. R. Cook
SP, Salt Point	474	SRWI	*Tsuga canadensis*	E. R. Cook
HL, Hobbs Lake	805	SRWI	*Pinus strobus*	R. P. Guyette
LD, Lac Duparquet	802	SRWI	*Thuja occidentalis*	S. Archambault
DL, Dixon Lake	433	SRWI	*Pinus resinosa*	E. R. Cook
SL, Swan Lake	909	SRWI	*Pinus strobus*	R. Guyette & B. Cole
RM, Riviere du Moulin	459	SRWI	*Tsuga canadensis*	E. R. Cook
GB, Gibbs Brook	473	SRWI	*Tsuga canadensis*	E. R. Cook

[a] PDSI, Palmer Drought Severity Index; SRWI, Standardized Ring Width Index

years were emphasized, ensuring that some part of the sequence covered the time period of interest, A.D. 400 – 1650.

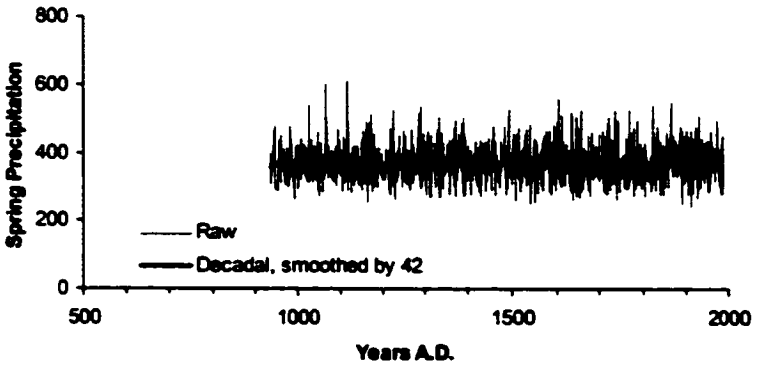


Figure 202. **Raw and decadally-averaged, 42-smoothed spring precipitation estimates for the southeastern United States.**

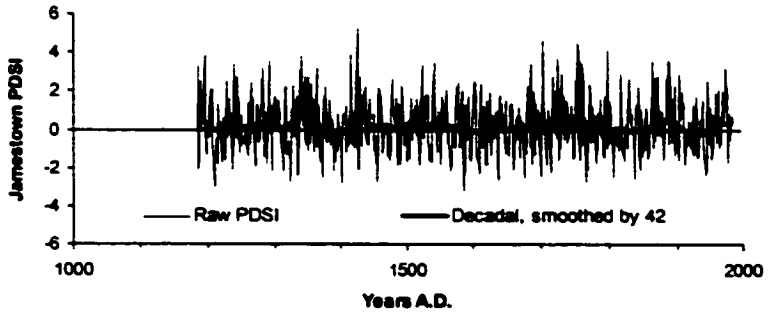


Figure 203. **Raw and decadally-averaged, 42-smoothed PDSI values for the Jamestown/Roanoke region.**

Although the beauty of dendroclimatological sequences lies in the precisely-dated data they provide on climatic variability on interannual and decadal time scales, low frequency changes that might reflect regional climatic changes are the primary concern here. Tree ring chronologies are not well-suited to such an endeavor because low frequency variation is often removed during the ring width standardization process. In an attempt to access these low frequency changes, 10-year averages were calculated for each sequence, followed by a 42 smoothing

algorithm. Figures 204 – 208 show the individual sequences of ring width indices, comparing for each the raw and smoothed data sets. The smoothed sequences appear to do a fair job reflecting the major trends in the raw ring width indices.

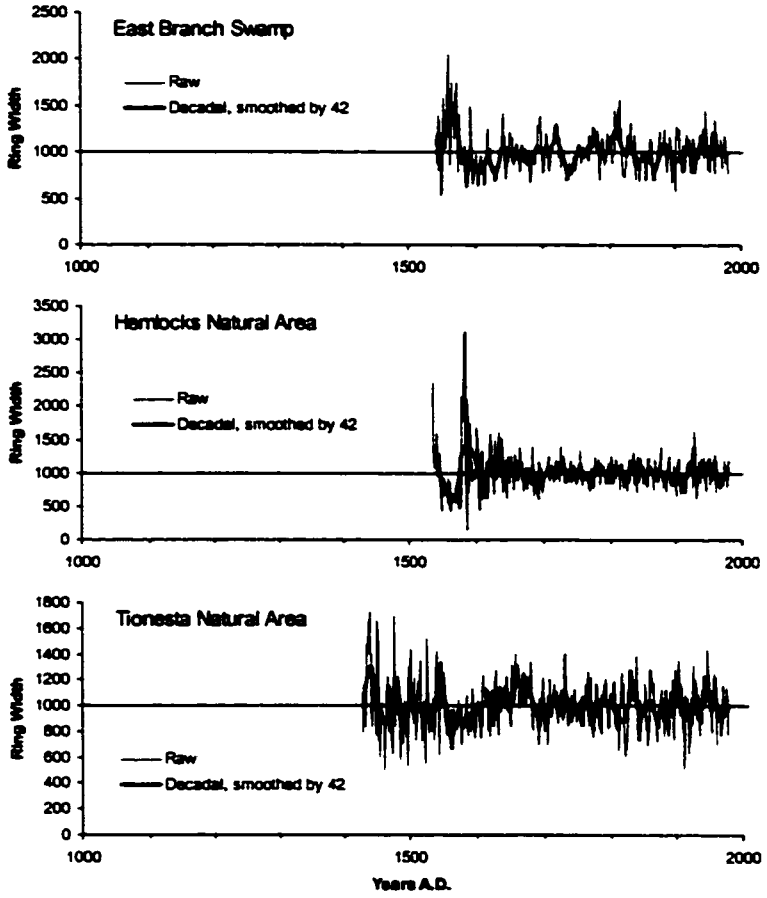


Figure 204. **Raw and decadally-averaged, 42-smoothed standardized ring width indices for sequences in central Pennsylvania.**

These sequences display considerable variation in the timing and nature of recorded climatic conditions, but there are events which appear simultaneously in all or nearly all sequences. For example, consider the severe droughts dating to 1587 – 1589 and 1606 – 1612 as documented in the Jamestown/Roanoke sequence (Stahle et al. 1998). Although varying in terms of

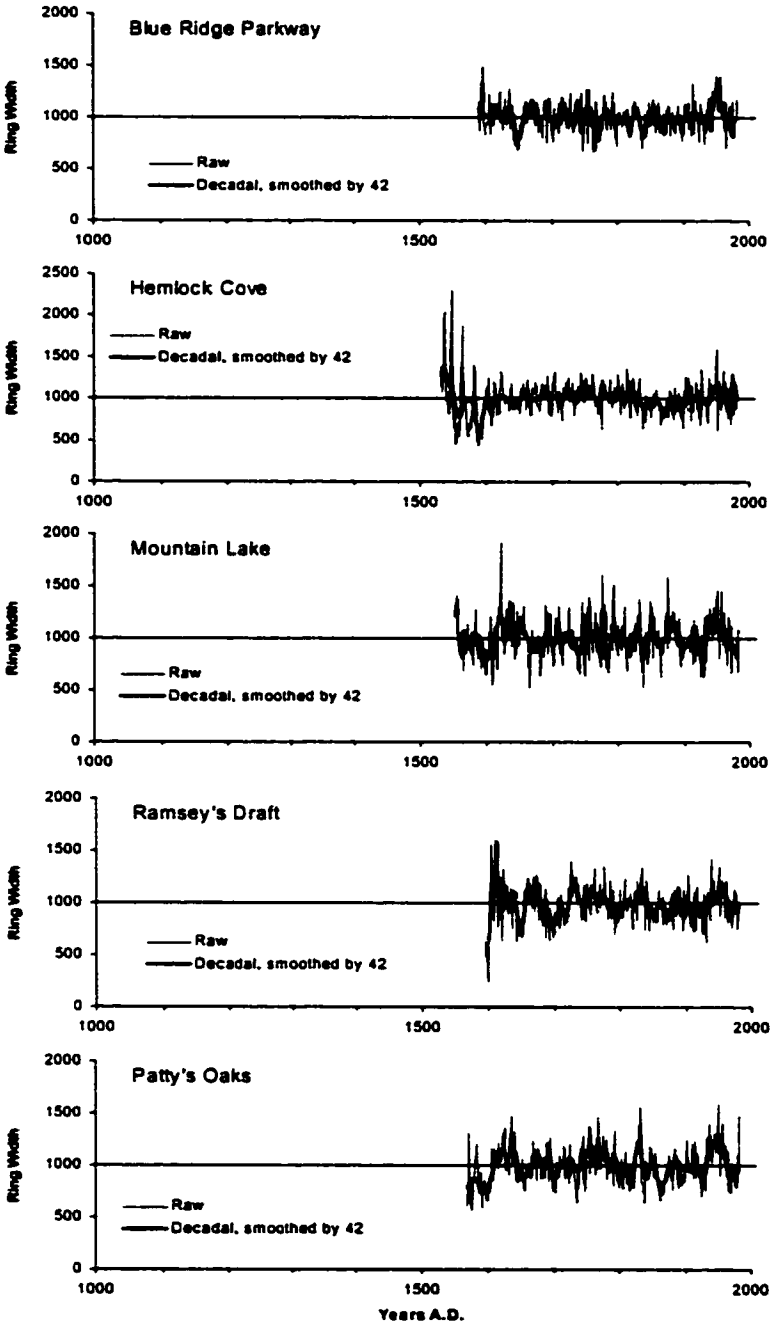


Figure 205. Raw and decadally-averaged, 42-smoothed standardized ring width indices for five tree ring sequences from the southeastern United States.

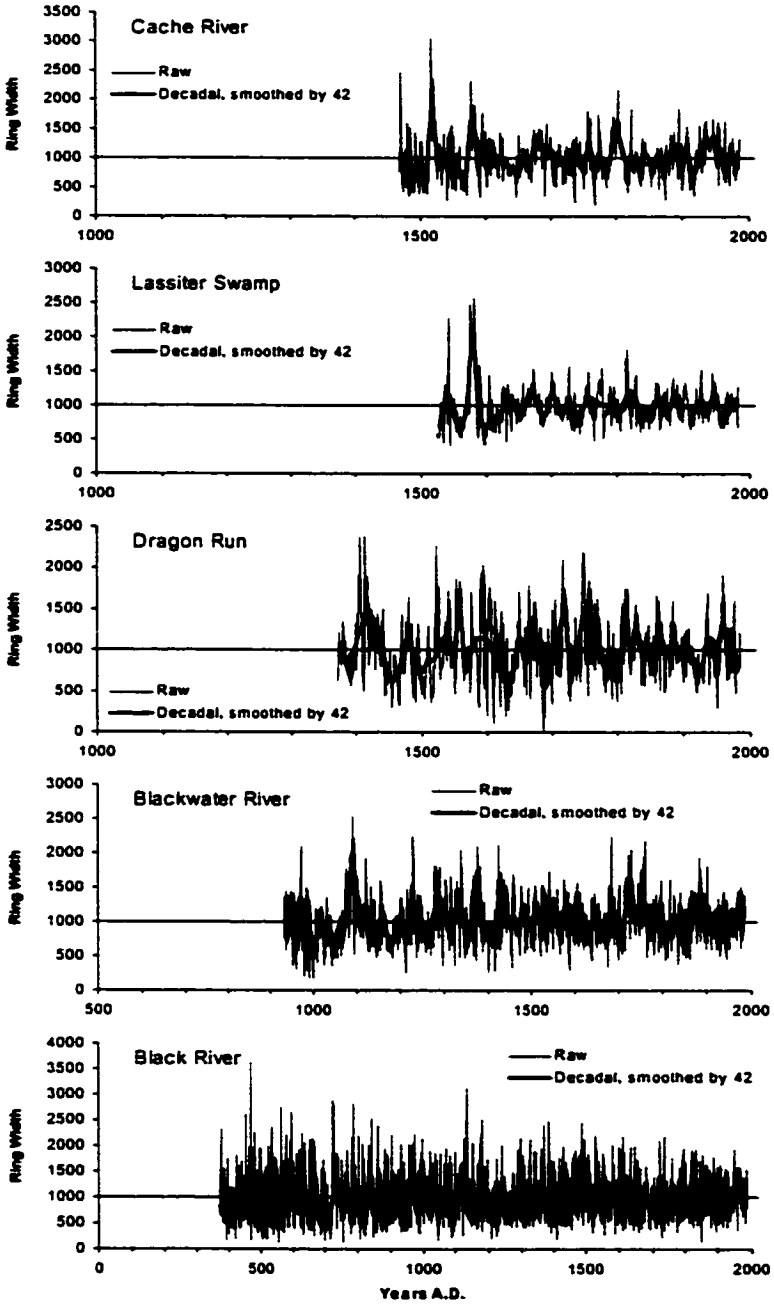


Figure 206. Raw and decadally-averaged, 42-smoothed standardized ring width indices for five tree ring sequences from the southeastern United States.

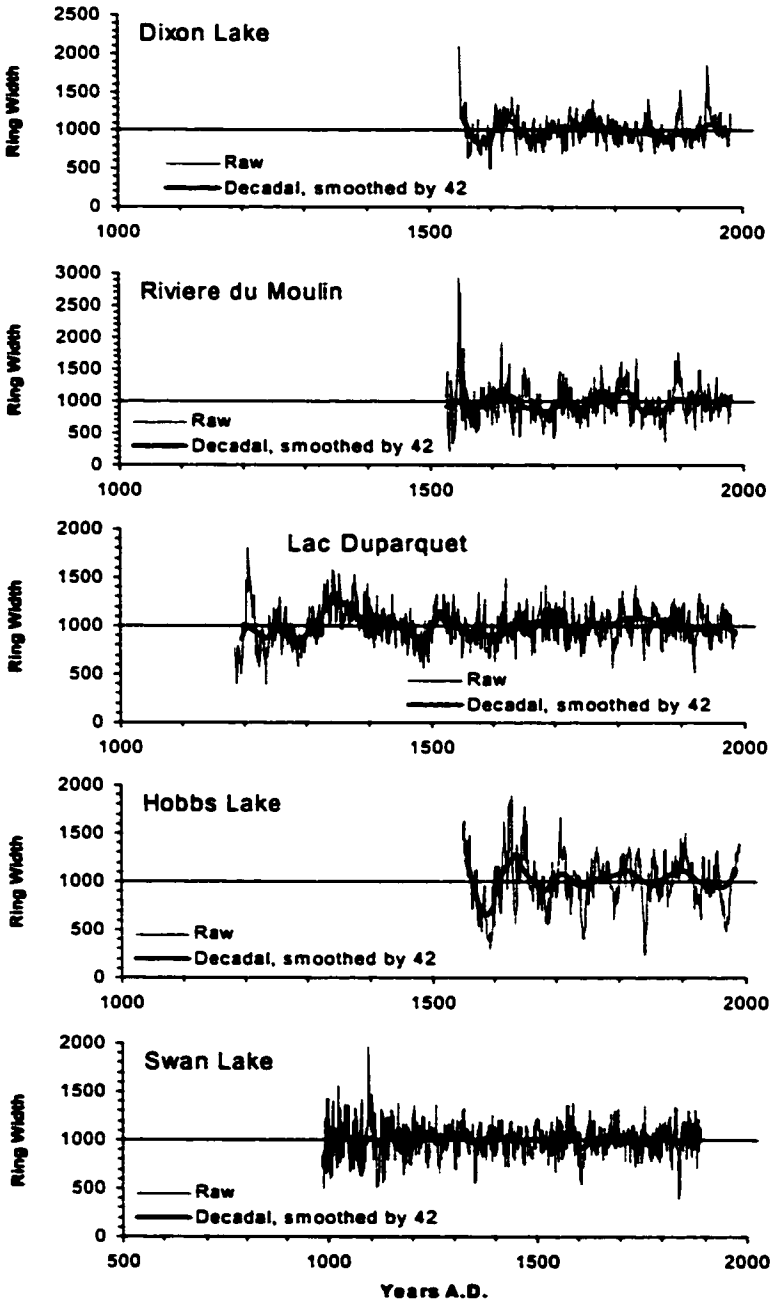


Figure 207. **Raw and decadally-averaged, 42-smoothed standardized ring width indices for five tree ring sequences from north of the study area.**

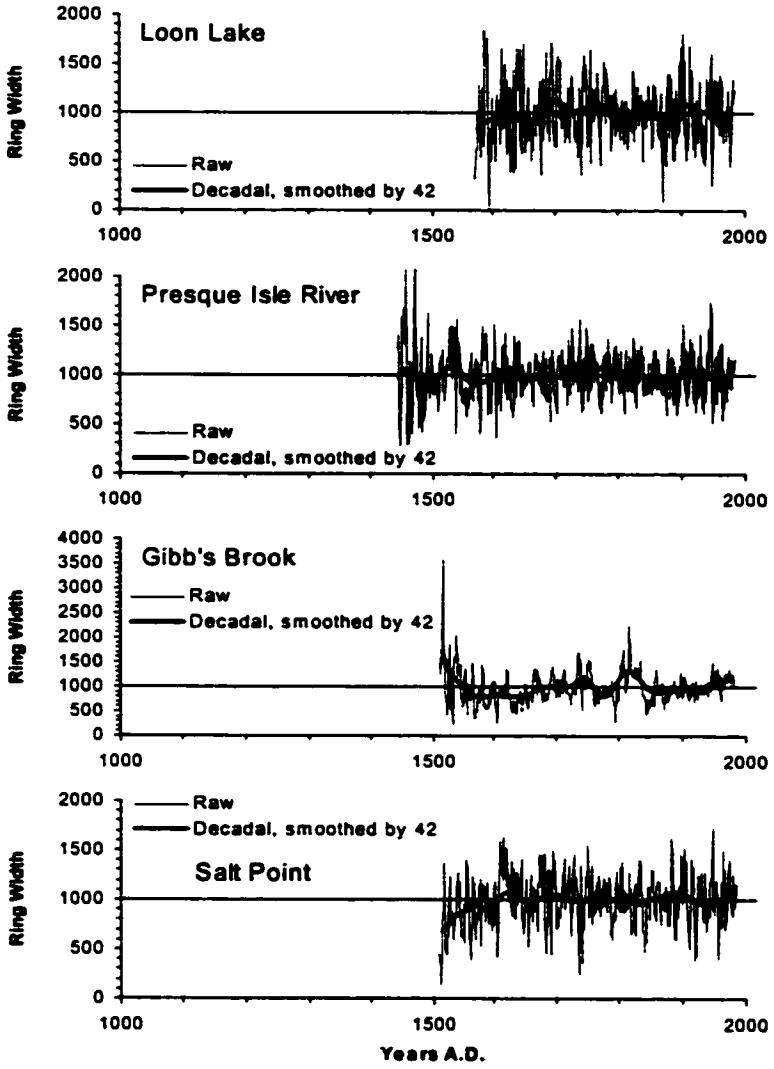


Figure 208. **Raw and decadally-averaged, 42-smoothed standardized ring width indices for four tree ring sequences from north of the study area.**

intensity and duration, these events are also recorded in several sequences from elsewhere in the Southeast, central Pennsylvania (cf. Richardson and Anderson 1999) and eastern Canada. The historic droughts of the mid-1800s and the 1930s are also represented in several sequences. There is reason to believe, then, that large-scale climatic phenomena like these might have affected the Ohio Valley, too.

The decadally-averaged, 42-smoothed ring width sequences were combined as listed in Table 95 to comprise three main regional sequences, in addition to the Jamestown/Roanoke PDSI and the southeastern spring precipitation data. These dendroclimatological sequences are all shown in Figure 209. Only spring precipitation estimates needed to be rescaled for plotting purposes; here they are plotted as % deviations from the mean. Clearly, there are major differences in the amount of time covered by the different sequences. It is unfortunate that the earliest part of the sequence is represented only in the Southeast. With the addition of the reconstructed spring precipitation (which includes one location [Black River] also included in the southeastern ring width sequence) and the northern ring width sequences in roughly A.D. 950, there appears to be some correlation in the timing of peaks and valleys (although the northern sequence lags a bit). After A.D. 1450, however, the record indicates considerable regional variation in the timing, direction and magnitude of climatic change.

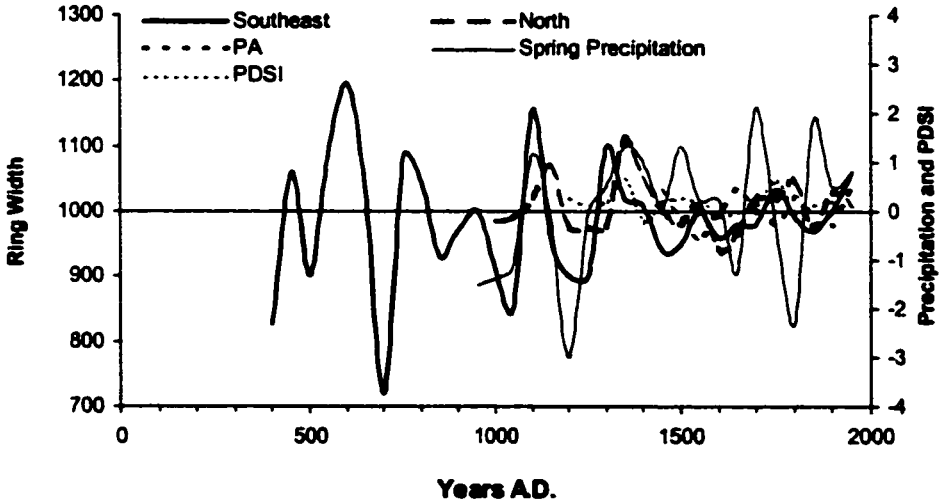


Figure 209. **All dendroclimatological sequences summarized.**

Figure 210a plots the standardized ring width indices for the southeastern series against the incidence of beach ridges and the mesic index.

Although not significantly correlated (r = -.025 and .062 against beach ridges and the mesic index, respectively), some peaks and valleys do appear in concert, particularly between ring width and the mesic index. Indeed, in every case where the mesic index increases, there is a corresponding peak in the southeastern ring width index. There are a few ring width peaks that are not in concert with the mesic index, however. The tree ring sequences of the Southeast reflect greater

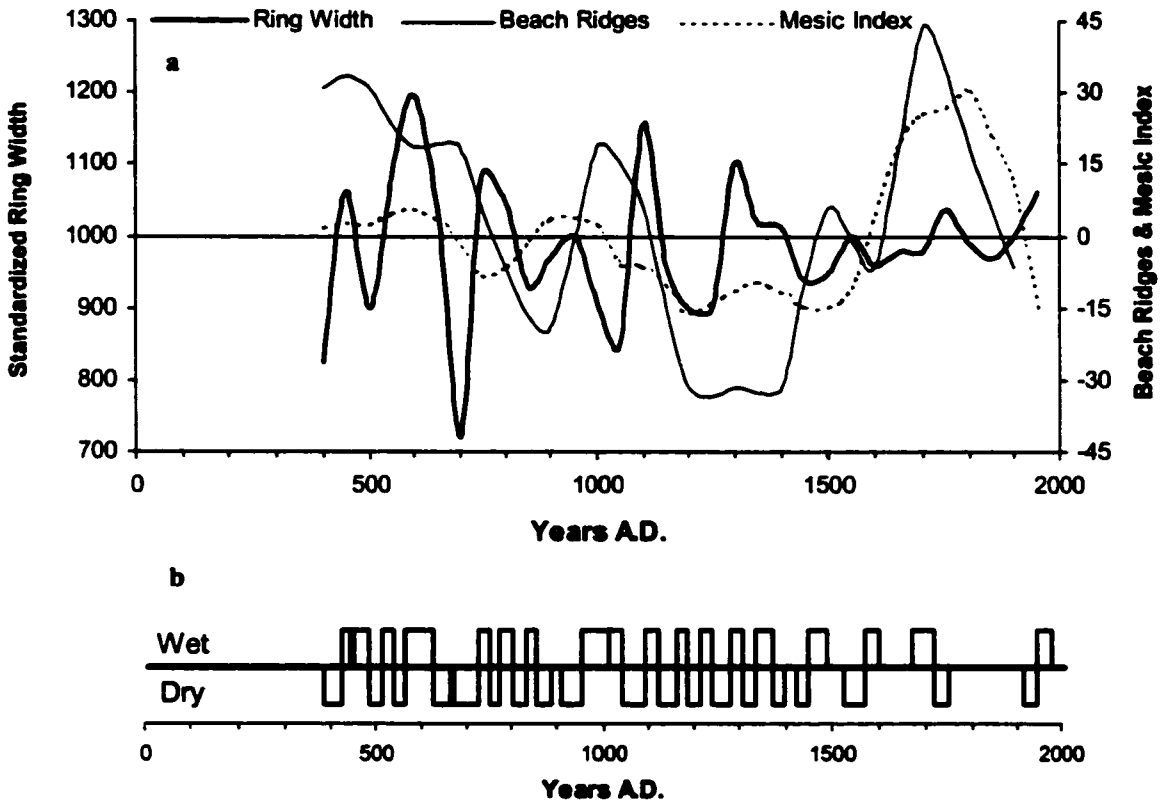


Figure 210. **Southeastern dendrochronological data.** (a) Standardized ring width indices from the southeastern regional sequence with incidence of beach ridges and the mesic index. (b) Statistically significant wet and dry regimes identified in the June PDSI reconstructed from dendroclimatic data at Black River, NC (Stahle et al. 1988).

climatic variation, in part because they are more sensitive records of climatic change than pollen deposits, and perhaps in part because the southeastern United States experienced greater variation in precipitation and/or temperature. In either

case, the climatic fluctuations documented by the mesic index and, to a lesser extent, the beach ridges appear to be confirmed by the southeastern tree ring record.

June Palmer Drought Severity Index (PDSI) values have been reconstructed for one of the southeastern dendroclimatic sequences, a swamp forest along the Black River in North Carolina (Stahle et al. 1988). The PDSI is a measure developed to indicate the degree to which actual precipitation at some time and place departs from climatically "normal" precipitation then and there (Palmer 1965). The index is scaled such that positive values are considered precipitation excesses, while negative values are precipitation deficits. The severity of the drought or wet period is indicated by the index's absolute value; the larger the number, the more severe the climatic episode. Figure 210b shows the timing of statistically significant wet and dry regimes in North Carolina as presented by Stahle et al. (1988); the mean PDSI of each moisture regime was determined to be significantly wetter or drier than the mean PDSI for the preceding thirty year interval. Like with the ring width index shown in Figure 210a, there is some correspondence between the appearance of June PDSI wet regimes and peaks in the mesic index and beach ridge data, but the fit is far from perfect.

Spring (March/April - June) precipitation estimates were calculated from baldcypress (*Taxodium distichum*) ring-width sequences in Georgia, North Carolina and South Carolina by Stahle and Cleaveland (1992, 1994). Those data, smoothed and scaled as % deviations from the mean, are plotted in Figure 211 against the incidence of beach ridges, the mesic index, and annual precipitation (estimated from pollen data). Although overlapping peaks can be identified, there are no significant correlations (r = -.005, -.071, and -.125 versus beach ridges, mesic index and annual precipitation, respectively). That these fits were so poor proved surprising since Stahle and Cleaveland (1992) noted that precipitation extremes in that region are positively correlated with those located elsewhere in eastern North

America historically and that they appear to be accounted for by large-scale changes in atmospheric circulation.

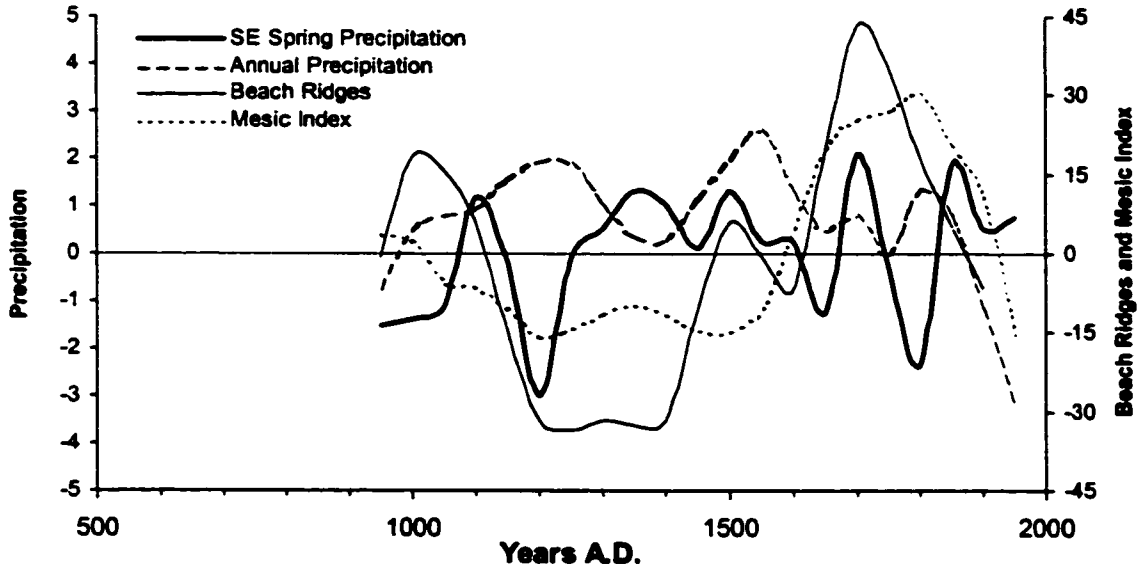


Figure 211. **Reconstructed spring precipitation in the Southeast with the incidence of beach ridges, annual precipitation and mesic index.**

Figure 212 plots reconstructed (and smoothed) July PDSI values estimated from baldcypress tree ring data from the Blackwater and Nottoway Rivers (Stahle et al. 1998) with the incidence of beach ridges and the mesic index. Although not statistically correlated (r = .010 and -.098 against beach ridges and the mesic index, respectively), peaks in the PDSI appear visually to correspond with the beach ridge data. Figure 213 plots the July PDSI sequence with annual precipitation and summer temperature (as estimated from pollen data). One might expect that the July PDSI should correlate positively with precipitation and negatively with temperature. That is not the case (r = -.139 and .182, precipitation and temperature, respectively); neither correlation coefficient is statistically significant.

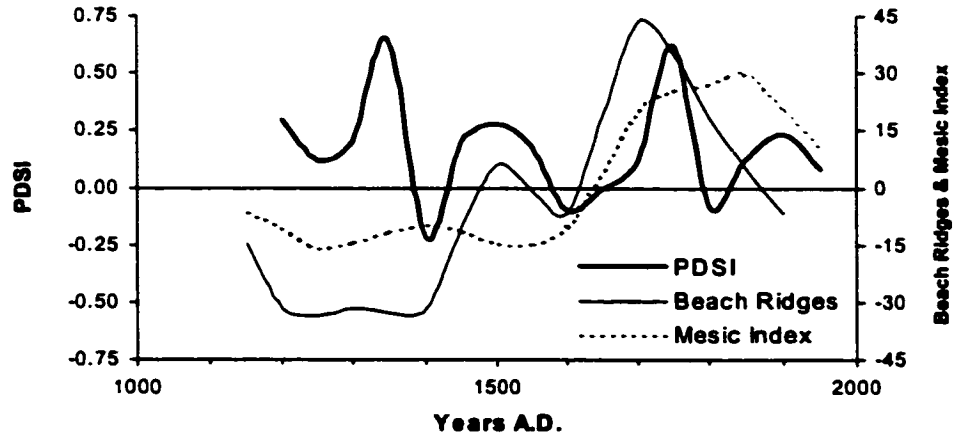


Figure 212. **Reconstructed PDSI values from the Jamestown/Roanoke area of southeast Virginia with the incidence of beach ridges and mesic index.**

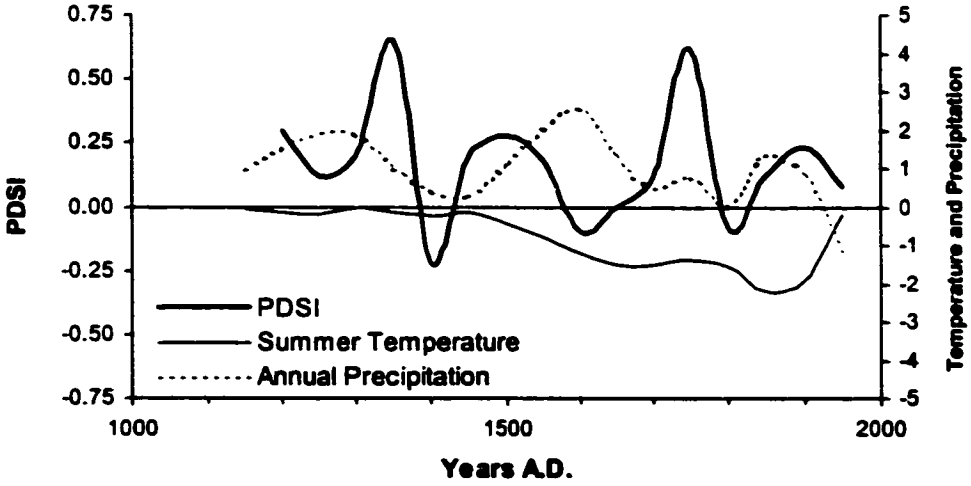


Figure 213. **Reconstructed PDSI values from the Jamestown/Roanoke area with annual precipitation and summer temperature.**

Standardized ring width indices were available for three dendroclimatological series of sufficient time depth in the study area (central Pennsylvania). As shown in Figure 214, these data do not correlate significantly

with either the incidence of beach ridges or with the mesic index (r = .116 and -.031, respectively). Correlations with annual precipitation and summer temperature are slightly better (r = -.290 and .302, respectively), but still not significant and certainly not in the direction expected.

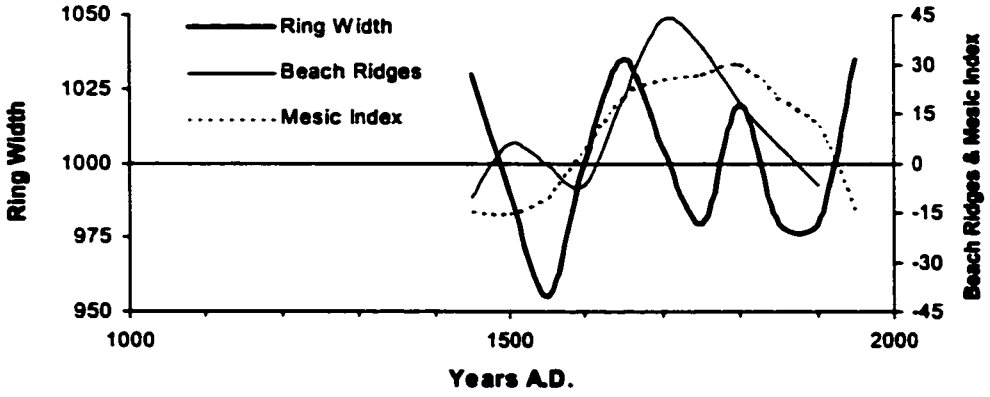


Figure 214. **Standardized ring width index for sequences from central Pennsylvania against the incidence of beach ridges and the mesic index.**

Finally, the last dendroclimatological data set, the northern sequence is considered. The smoothed data are plotted with the incidence of beach ridges and the mesic index in Figure 215. There appears to be some coincidence between larger growth rings and the mesic index, but again, it is not statistically significant (r = -.125 and -.020 with beach ridges and mesic index, respectively).

Certainly, the dendroclimatological data do not provide impeccable support for the climatic history derived from pollen and beach ridge data. Given differences in the scales of climatic phenomena they record and the geographic distance from the other sources of climatic data, perfect correlations were not anticipated. However, even at the gross scale of analysis conducted here, climatic changes as reflected by the mesic index, and to a lesser extent, by the incidence of beach ridges, appear to be represented also in the dendroclimatological sequences.

The major difference between these data sets was that, while the tree ring data often recorded climatic events coincident with those documented in e.g., the mesic index or beach ridge data, dendroclimatological sequences also recorded fluctuations not evident in those other sources.

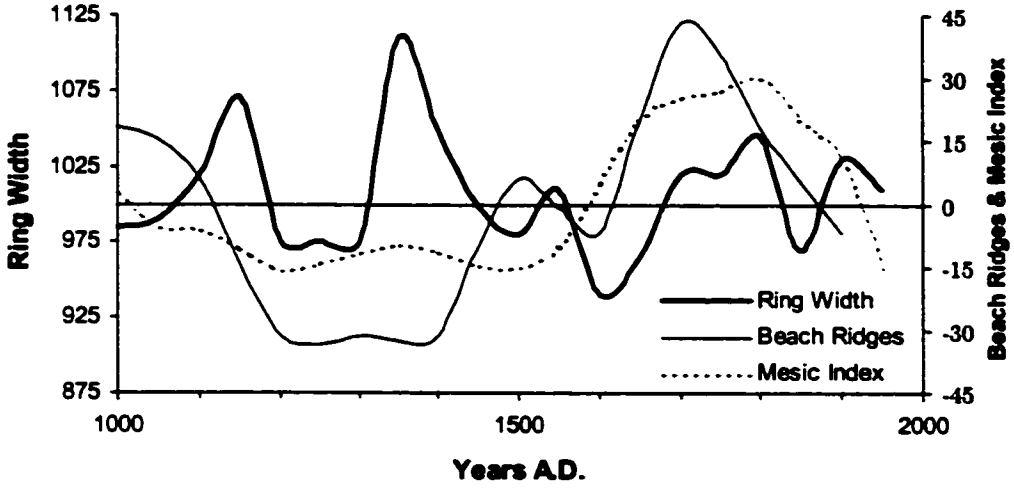


Figure 215. **Standardized ring width index for northern sequences against the incidence of beach ridges and the mesic index.**

A general summary of the dendroclimatological data follows. The southeastern tree ring data indicate relatively wet conditions prevailed from roughly A.D. 400 – 650; this is coincident with peaks in the mesic index and the beach ridge data already suggested to reflect warm, wet conditions. During the periods A.D. 650 – 750 and 950 – 1050, drought conditions prevailed; severe drought episodes in the Great Plains and the southwestern U.S. have been documented also for these time periods (Woodhouse and Overpeck 1998). The ring width indices of the Southeastern and Pennsylvanian sequences indicate peaks at roughly A.D. 1100 – 1150; these peaks correspond to cooler, wetter conditions as indicated by the mesic index and beach ridge data. Decreases in ring width at roughly A.D. 1200 are coincident with valleys in the mesic index and beach ridge data, and with well-documented droughts elsewhere (Woodhouse and Overpeck 1998). By A.D. 1350,

the tree ring sequences indicate a return to cooler/wetter conditions, which lasts until roughly A.D. 1450, again this parallels the mesic index and beach ridge curves. As indicated previously, most sequences record drought conditions during the late 1500s and early 1600s, as well as during the mid-1800s and 1930s. During the period A.D. 1700 – 1800, most sequences indicate cooler/wetter conditions, again consistent with the beach ridge and mesic index data.

As noted earlier, the tree ring data may provide some indication not only of changing mean climatic conditions through time, but also of climatic variation. That information could be useful in evaluating the hypothesis that the formation of beach ridges is a phenomenon of highly varying climate, rather than of cool/wet or warm/dry conditions. Decadal standard deviations were calculated for each of the standardized ring width records. These individual site records were combined to create northern, Pennsylvanian and southeastern sequences (Figure 216), which were then treated with a 42 smoothing algorithm. As before, for statistical comparison with other data sets, values were determined at 50-year intervals for each sequence.

Before comparing these data with other data sets, the impact that different ring widths might have on associated standard deviations needs to be considered. Higher mean ring widths might give rise to higher standard deviations than lower mean ring widths simply due to the values involved. Although one might be tempted to use coefficient of variations to eliminate such a pattern, such estimates are not appropriate for non-ratio scale data. No significant correlations were found between mean ring width and standard deviation for any of the sequences (North: $\rho = -.087$, $p = .717$; PA: $\rho = .093$, $p = .786$; Southeast: $\rho = .259$, $p = .153$). The potential for a regional pattern of variable climate is considered next. Even though the mean ring widths were not correlated among the three sequences, the standard deviations were. The Pennsylvania sequence, situated between the

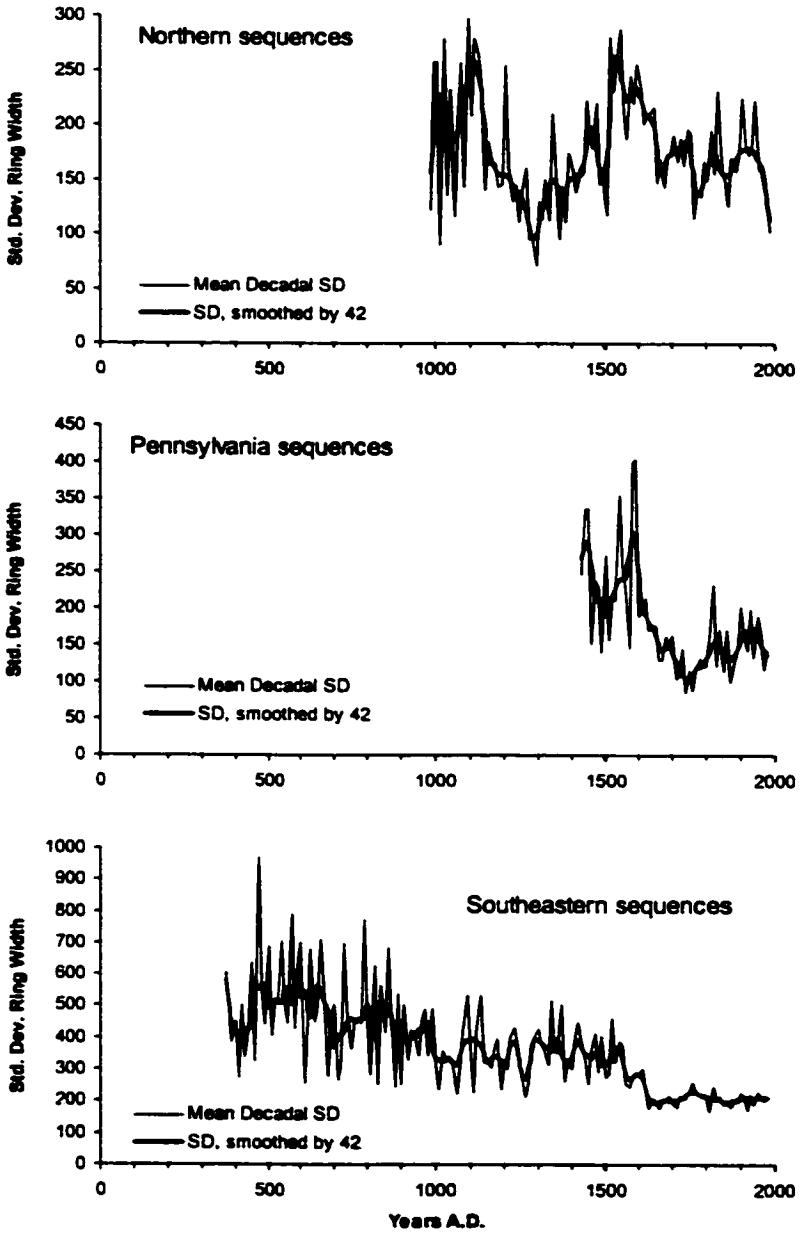


Figure 216. **Decadal standard deviations and 42-smoothed curves associated with standardized ring widths for tree ring sequences to the north and southeast of the study area and in central Pennsylvania.**

other two, was positively correlated with both the northern ($\rho = .628$; $p = .038$) and southeastern ($\rho = .656$; $p = .028$) sequences, but the latter two were not correlated

with each other (ρ = .125; p = .599). This would seem to indicate some, but not complete, linkage in episodes of variable climate over the past 400 years.

If beach ridge formation is associated with a variable climate, then the incidence of beach ridges should correlate positively with the decadal standard deviations documented in the tree ring record. As shown in Figure 217, the relationship is not a simple one. Statistically, the incidence of beach ridges correlates significantly and positively with the northern sequence (ρ = .482; p = .037) and negatively with the Pennsylvanian sequence (ρ = -.768; p = .010), but not significantly with the southeastern sequence (ρ = .094; p = .614). The northern sequence is clearly of more relevance here, given that several of the individual tree ring records that comprise the northern sequence are located within the Great Lakes watershed and that the weather systems that govern Great Lakes climate

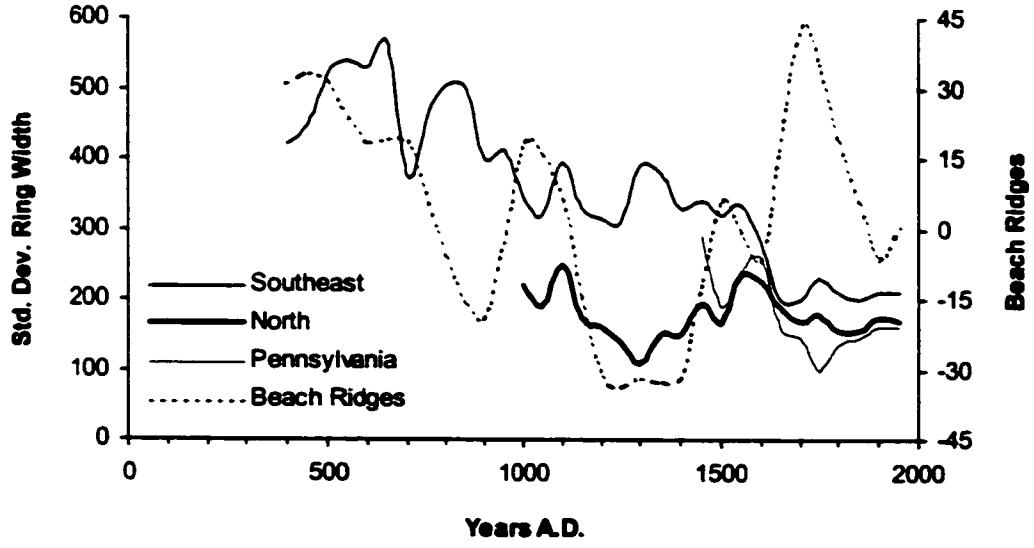


Figure 217. **Decadal standard deviations for northern, Pennsylvanian, and southeastern tree ring sequences versus the incidence of Great Lakes beach ridges.**

come from the North. Overall, the correlations suggest that beach ridge features form frequently during times of greater climatic variation and this may account for the varying relationships between the incidence of beach ridges and other paleoclimatic data.

BOREHOLE TEMPERATURE RECORDS

The pollen, beach ridge and tree ring data appear to present a fairly coherent picture of climatic change over the past 2000 years. There is one other set of proxy climate data that may add to our understanding of paleoclimate: borehole temperature records.

There are two primary sources for the Earth's subsurface temperatures: heat flow from the center of the Earth toward the surface and heat flow from the surface toward the center of the Earth. It is the latter, the propagation of ground surface temperatures into the subsurface as the rocks of the Earth's crust conduct heat downward, that is of interest to geophysicists who wish to reconstruct ground surface temperature histories. Using subsurface temperature profiles, obtained by lowering a thermistor down drilled boreholes and recording the temperature at known depths, they seek to identify departures from the steady-state geothermal gradient that can be ascribed to past temperature fluctuations at the surface.

The deeper the thermal departure or perturbation, the older the surface temperature event that created it. There is some attenuation of the temperature signal as depth and time increase, with short-term (high frequency) fluctuations attenuating more rapidly than long-term (low frequency) ones. Thus, the top meter or so reflects the daily temperature cycle, the next 15 meters record seasonal oscillations, and the following 500 or more meters record a continuous record of the long term (century-scale and greater) temperature history (Bodri and

Cermak 1997; Pollack and Chapman 1993). The resulting loss of detail with increased age of the subsurface temperature record decreases the resolution with which earlier climatic fluctuations can be reconstructed. Thus, while Bodri and Cermak (1997) were able to reconstruct trends in the ground surface temperature history over the past 32,000 years from a 6,000 m deep borehole in the Czech Republic, they were unable to identify some early short-term climatic fluctuations documented by other independent data sources.

Generally, a good relationship exists between subsurface temperatures and historic surface air temperature records from meteorological stations (Baker and Ruschy 1993; Chapman et al. 1992; Chisholm and Chapman 1992; Gosnold et al. 1997; Harris and Chapman 1995; Majorowicz and Skinner 1997; Putnam et al. 1994). The correlation is not a perfect one, however, because of complexities in the process of heat transfer between the air and the ground. Terrain effects (variation in hydrology, vegetation cover, topography and lithology) can alter the relationships between air, ground surface, and subsurface temperatures. For example, snow cover, soil moisture, forest vegetation, and nearby water bodies can act as insulators, keeping the ground from reaching the low air temperatures of winter and the high temperatures of summer (Beltrami and Mareschal 1991; Chapman et al. 1992; Lewis and Wang 1992b; Mareschal and Beltrami 1992). Additionally, variable lithology and flowing ground water can modify the regime of thermal conduction, consequently distorting the subsurface temperature signal (Drury et al. 1984; Harris and Chapman 1995). Thus, while subsurface temperature profiles are considered to be direct thermophysical records of past ground surface temperatures, they are not necessarily undistorted and will not correspond exactly to past climates.

Given that the terrain can introduce variability which might be mistaken for climatic change (Beck 1992; Chisholm and Chapman 1992; Deming and Borel 1995; Gosnold et al. 1992; Jessop 1990; Lewis and Wang 1992a, 1992b;

Pollack et al. 1993; Stepaniak et al. 1992; Wang et al. 1992), it is imperative that researchers identify and either exclude or correct mathematically boreholes that are significantly so affected. The location of each borehole is evaluated with respect to several criteria, including the local topography (e.g., valley vs. hilltop situations), its exposure, the proximity of nearby water bodies, the potential for previous surficial erosion or burial, and land clearance or other urban disturbances. Borehole lithological assessments often include measurements of thermal conductivity, porosity and composition (the latter to ensure that there are not significant concentrations of heat-producing radioactive elements [e.g., U, Th or K]). Identifying perturbations to the subsurface temperature record due to groundwater flow is a particularly vexing problem. Lewis and Wang (1992a) noted that remeasuring the temperature profile of boreholes at a later date can detect changes due to groundwater movement, while Drury et al. (1984) showed that precise temperature measurements at closely spaced intervals can pinpoint thermal disruptions due to water flow. Even with these screening tactics, it is virtually impossible to guarantee for any particular borehole that terrain effects have not modified the subsurface temperature profile. As a consequence, researchers rely heavily on multiple drillholes from a region. Because not all boreholes will be identical with respect to terrain, common temperature perturbations are more likely to reflect climatic change (Beltrami and Mareschal 1995; Deming and Borel 1995; Lewis and Wang 1992b).

Once the terrain factors that can influence ground and subsurface temperatures are accounted for, it becomes a matter of physics to model the geothermal gradient at a location and subtract it from the temperature profile to reveal the sequence of perturbations in ground temperature that result from air temperature changes. The inversion models used to transform borehole temperature profiles into ground surface temperature histories vary in the complexity of their algorithms (Beck 1992; Nielsen and Beck 1989) and comparisons show the solutions produced can vary depending upon the nature (e.g.,

measurement precision, noise levels) of the data available, the parameters estimated, and the theoretical constraints imposed (Beck et al. 1992; Beltrami and Mareschal 1995; Clow 1992; Huang et al. 1996; Shen et al. 1992, 1996). In general, though, the ground temperature histories provided by different models agree with respect to the broad trends, while conflicting slightly on details such as the specific timing and magnitude of climatic changes. These temperature histories appear to be consistent with dendrochronological, oxygen isotope, and other proxy records (Beltrami and Chapman 1993; Beltrami et al. 1992; Beltrami and Mareschal 1992; Beltrami and Taylor 1995; Bodri and Cermak 1997).

Subsurface temperature profiles for hundreds of boreholes throughout North America, many in Canada, have been logged, evaluated, and inverted to produce ground temperature histories. The vast majority of the ground temperature histories so produced focus on the past 500 to 1000 years due to research emphasis on tracking the most recent global warming event, the drilled depth of many boreholes, and the loss of resolution that attends older climatic events. Not surprisingly, though, these ground temperature histories reveal significant regional variation (Beltrami and Mareschal 1992; Deming 1995; Majorowicz and Skinner 1997; Wang et al. 1994). For example, borehole profiles reflect the most recent warming event by temperature increases over the past 100 – 200 years of 2 – 4 °C in Alaska (Lachenbruch and Marshall 1986), 1 – 3 °C in central Canada (Majorowicz 1993; Majorowicz and Skinner 1997), 1 – 2 °C in eastern Canada (Wang and Lewis 1992; Wang et al. 1992, 1994), 1.5 – 2.5 °C in the northeastern U.S. (Pollack et al. 1993), 0.4 – 2.0 °C in the northern U.S. plains (Gosnold et al. 1992, 1997), 0.4 – 0.8 °C in Utah (Chisholm and Chapman 1992; Harris and Chapman 1995), and 1.25 – 1.5 °C in northcentral Oklahoma (Deming and Borel 1995). While one might argue that this variation is a function of different inversion models, there is a latitudinal gradient in the magnitude of warming, with southern locales recording less ground temperature warming than northern locales

(Gosnold et al. 1997; Pollack and Chapman 1993); variation in the timing of the warming event in each region, however, is not similarly patterned.

Borehole temperature data are available as part of the World Data Center-A for Paleoclimatology, administered by the NGDC Paleoclimatology Program (http://www.ngdc.noaa.gov/paleo/borehole/). Figure 218 shows and Table 96 lists a sample of boreholes near the study area with available temperature data dating back to A.D. 1500. The subsurface temperature profiles at these sites have been inverted with a standardized procedure that seeks to ensure comparability among different records.

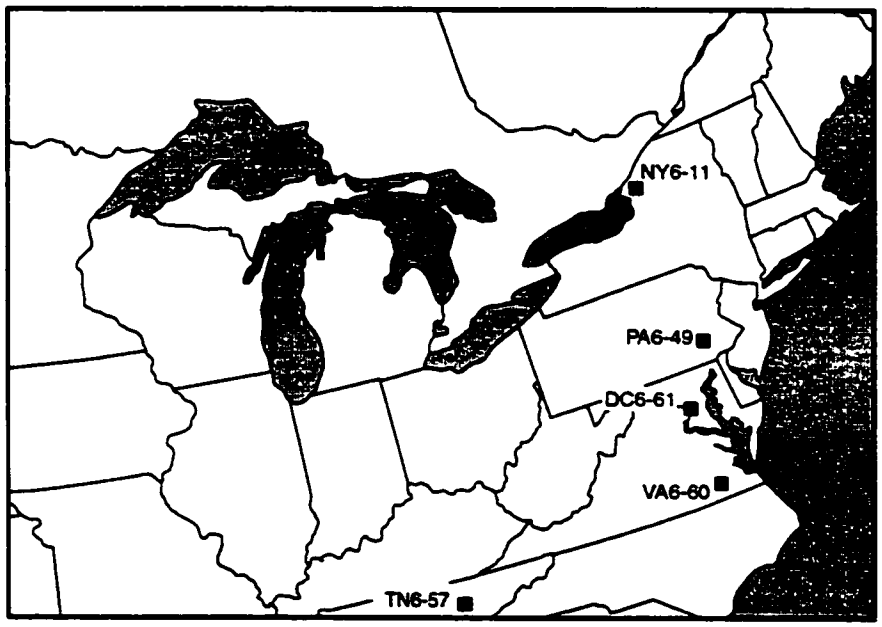


Figure 218. **Location of boreholes identified in Table 96.**

The inverted temperature profiles are plotted in Figure 219. The profiles have been scaled such that T_o, the mean ground surface temperature prior to A.D. 1500, is at 0.0 for each profile. Also shown in Figure 219 is the sequence of reconstructed summer temperatures (estimated from pollen data), corrected such that the mean temperature prior to A.D. 1500 (roughly 18.9 °C) is plotted as T_o = 0.0. There is variation in the shapes of the individual borehole temperature profiles

that includes both regional variation in ground surface temperatures and variation due to different perturbations that the boreholes may have experienced that are not corrected by the standardized inversion algorithm. All, however, show significant overall warming (on the order of 1 – 2°C) over the past 500 years.

Table 96. Borehole site number, contributor to the NGDC data base, and mean ground surface temperature prior to A.D. 1500 (T_0).

Borehole Site Number	Contributor	T_0 (°C)
US-DC6-61	W. Diment	12.6
US-PA6-46	T. Urban	10.1
US-NY6-11	T. Urban	6.6
US-TN6-57	W. Diment	13.0
US-VA6-60	W. Diment	14.2

Average summer temperature reconstructed from pollen records has not recovered after Little Ice Age cooling to the level of the pre-A.D. 1500 mean (Figure 219). The summer temperature profile plotted here is an average of the eastern and western pollen sequences (plotted in Figure 197). Figure 192c shows that the eastern and western sequences diverged over the past 500 years; accordingly, one might expect that the eastern sequence would more closely mimic the borehole temperature profiles, given their geographic proximity to the eastern pollen sites. Surprisingly, this is not the case; the eastern sequence shows considerable declines in summer temperature, while the western sequence records recent temperature increases of roughly the same magnitude as the borehole records. This suggests that, in eastern North America at least, the recent ground surface temperature warming shown in borehole temperature profiles may be due primarily to increasingly warmer winters. This is consistent with observations of climatic change during the historic era based on data obtained from the network of U.S. meteorological stations (Karl et al. 1995c).

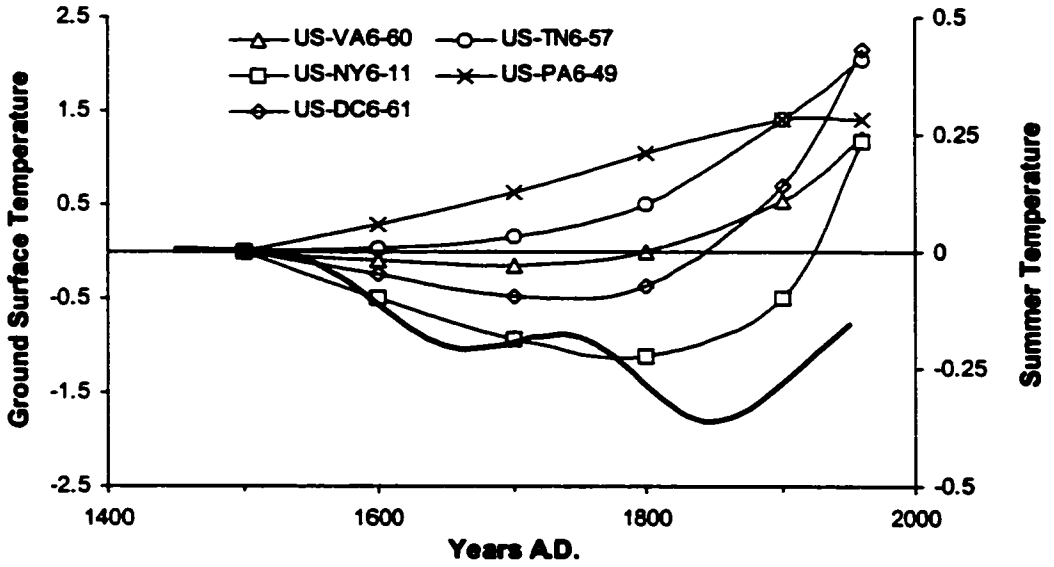


Figure 219. **Borehole temperature profiles versus the sequence of summer temperatures estimated from pollen data (bold), all plotted as °C deviations from T_o, mean temperature prior to A.D. 1500.**

Although few are published, longer borehole profiles typically indicate warmer temperatures at A.D. 1000, coincident with the Medieval Warm Period. As an example, consider ground temperature histories derived from boreholes located in four regions of eastern Canada (Figure 220). The curve for each of the regions, except Nova Scotia, represents an average of several borehole temperature profiles that were screened for terrain effects and determined to show similar perturbations prior to being inverted simultaneously (Beltrami and Mareschal 1992). They show a period of relatively warm temperatures around AD 1000, prior to cooling attributed to the Little Ice Age. Deeper boreholes, which contain longer temperature histories, also show a poorly resolved warm period extending from about 0 – 1000 AD (Beltrami and Mareschal 1992; Nielsen and Beck 1989). The Little Ice Age, marked by a gradual drop in temperatures, reached a low from 1750 – 1810 in eastern Canada. Temperatures have increased over the past 150 years, with a brief cooling episode around 1950, followed by renewed warming in the eastern regions.



Figure 220. **Ground temperature histories for four regions north of the study area.** NS, Nova Scotia; WO, western Ontario; SQ, southern Quebec; CO, central Ontario. Data from Beltrami and Mareschal (1992).

As it now stands, borehole temperature profiles are not particularly useful for teasing out subtle temperature changes that predate the past couple hundred years. Perhaps as researchers become more adept at identifying and compensating for perturbations and as inversion algorithms become more sophisticated, the time scale of temperature profiles will be lengthened.

MACROPHYSICAL CLIMATIC MODELS

There is one final potential source of information about past climate in the study area: macrophysical climatic models. Macrophysical climatic models simulate past climatic conditions for particular areas at particular times. To do so, they rely on estimates of variables such as the area of global glacial ice and incoming solar radiation, allowing for modulations by albedo and volcanic aerosols, and on models of atmospheric circulation (Bryson 1992; Bryson and Bryson 1997a, 1997b). Put simply, the model reconstructs variation in atmospheric circulation for a region through time. Synoptic climatology, which describes the historic relationship between climate and atmospheric circulation patterns (e.g., location of the jet stream during different seasons) at a location, is then used to establish

climatic conditions that correspond to the modeled patterns of atmospheric circulation.

The results of macrophysical climatic simulations for two locations in the study area (Portsmouth-Sciotoville and Miami University) were kindly shared by R. A. Bryson of the Center for Climatic Research, Institute for Environmental Studies, University of Wisconsin – Madison. Although these data are first approximations, and his study is not yet finished, the results merit consideration. Only the most recent 2000 years of a 14,000 year model is of interest here. Thus, there is some danger in focusing on a small piece of a much larger general climatic model. Figures 221 presents estimates of changes in annual precipitation and July and January temperatures for those two locations. For scaling purposes, the data are presented as % deviations from the 2000-year mean. Bryson and Bryson (1997a) note that, due to a programming glitch, climatic fluctuations in their models appear in the simulations approximately 100 years earlier than they should. To correct for that, 100 years have been subtracted from the age of each data point. In addition, although the original simulation time scale is in radiocarbon years, the time scale here has been converted to calibrated years A.D. to facilitate comparison with other climatic data.

According to the models, the historical trajectory of annual precipitation apparently differed between the two locations. This is not unexpected given that precipitation is a highly localized phenomenon, influenced by factors such as local and regional topography. The timing of changes in this plot does correspond to climatic events documented in the pollen record (Figure 222), even if the specific direction of change is not in agreement. For example, there is pollen evidence for increased precipitation in A.D. 300 and decreased precipitation after A.D. 1550 (although the latter shows fluctuations in an overall decreasing pattern, rather than a smooth trajectory shown by the model). That the climatic models and the pollen data are not in complete agreement are potentially explained by two observations.

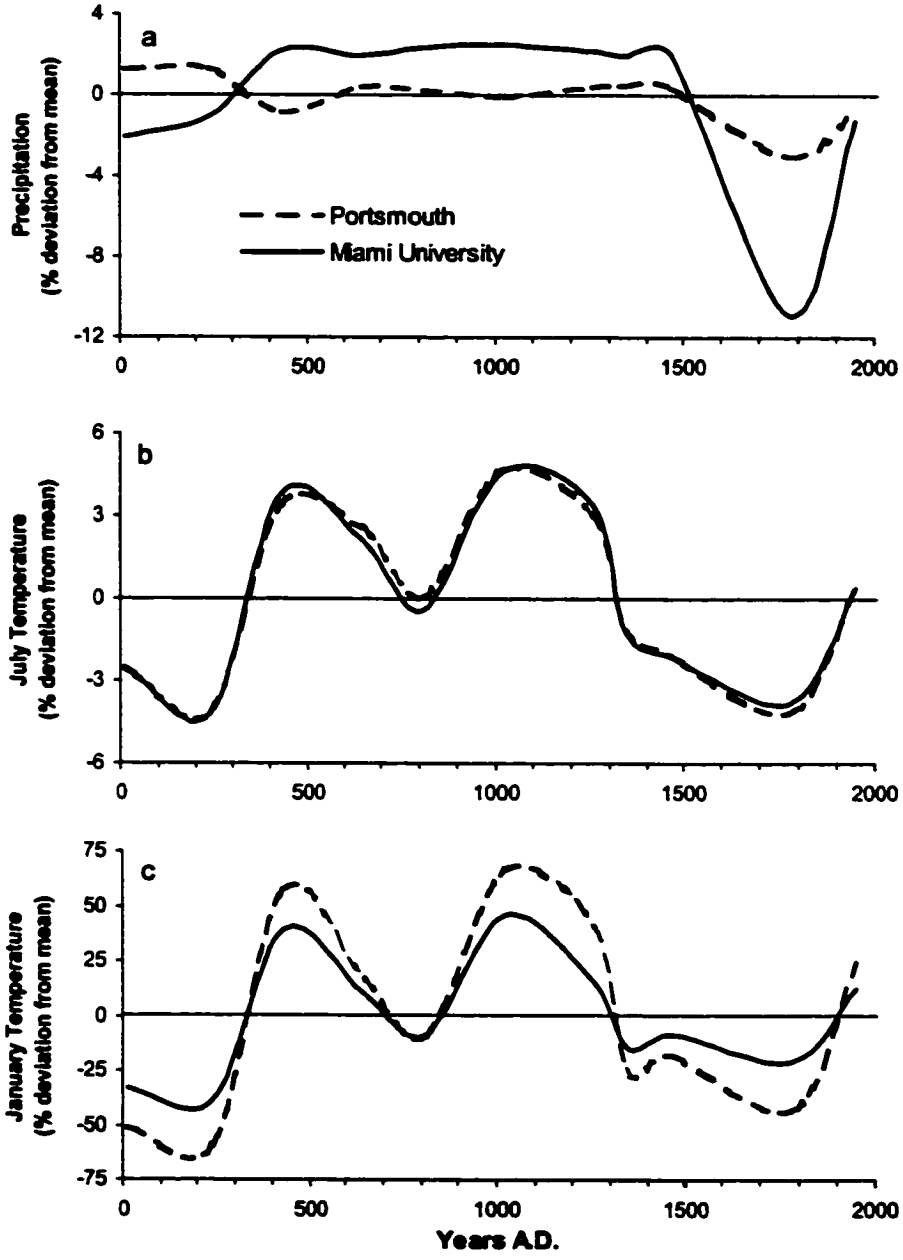


Figure 221. **Changes in (a) annual precipitation, (b) July temperature, and (c) January temperature as modeled by macrophysical climatic simulations.**

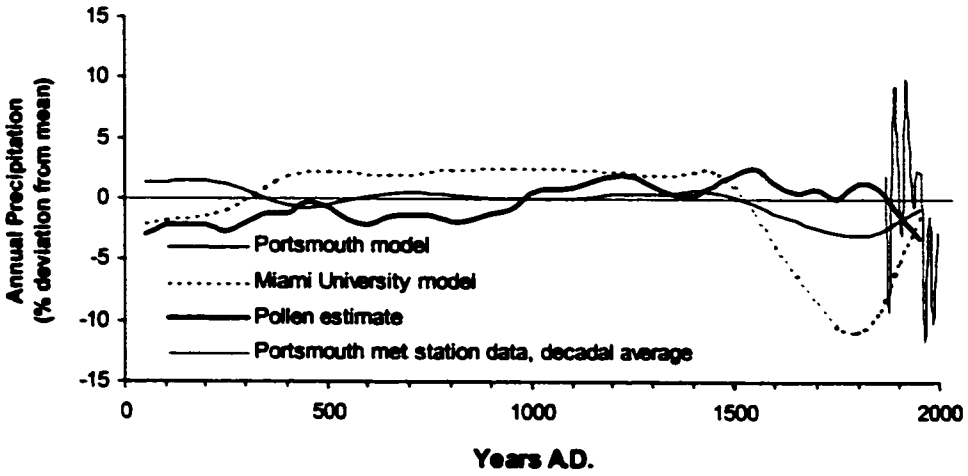


Figure 222. **Annual precipitation, as estimated by macrophysical climatic models for Portsmouth and Miami University, plotted against precipitation estimates from pollen records and historic met station data.**

First, because precipitation varies so greatly on a regional scale, the specific precipitation history at Portsmouth-Sciotoville, OH, is not likely to match closely that at Hell's Kitchen Lake, MN, for example. Second, even though the equations used to estimate annual precipitation from pollen production and deposition attempted to eliminate other factors (e.g., temperature, soil moisture, fire frequency), it is unlikely they were completely successful; indeed, that the explanatory power of the regression equation for precipitation was only 15% suggests more work remains to be done on that front.

There are some differences between the precipitation models and other proxy data sets. The tree ring, beach ridge, and salinity data do not support the notion of a significant and prolonged decrease in precipitation at A.D. 1500. Although there is evidence for several drought episodes in eastern North America during the historic era, there is no reason to believe that precipitation behaved in the manner shown. Droughts did not continually worsen from A.D. 1500, reaching a peak of severity in A.D. 1800, and then lessening until recent times. Precipitation records from the meteorological station at Portsmouth-Sciotoville that cover the

past 136 years do, however, indicate an increase in annual precipitation over the first part of that time period that parallels the Portsmouth model prior to a more recent decrease in precipitation that is not covered by the model (Figure 222).

The reconstructed temperature histories shown in Figures 221b and 221c are not only quite similar between the two models, but they agree more closely with many aspects of the proxy data sets than do the precipitation histories. In Figure 223, the July temperature models are plotted with the JJA temperature history derived from pollen assemblages. The plots are virtually parallel from A.D. 100 – 850, indicating relatively warm temperatures from roughly A.D. 350 – 700. A second peak from roughly A.D. 850 – 1300 in the macrophysical climatic models is not evidenced in the mean pollen data plotted here, but I note that the individual temperature records from Conroy, Basin and Dark Lakes (and perhaps from Lake of the Clouds, as well) do suggest a slight temperature increase at that time. This peak, coincident with the timing of the Medieval Warm Period, is also concurrent with a peak in the mesic index. The plots again are nearly parallel from A.D. 1350–1950, indicating a cooling event, followed by warming. The post-A.D. 1500

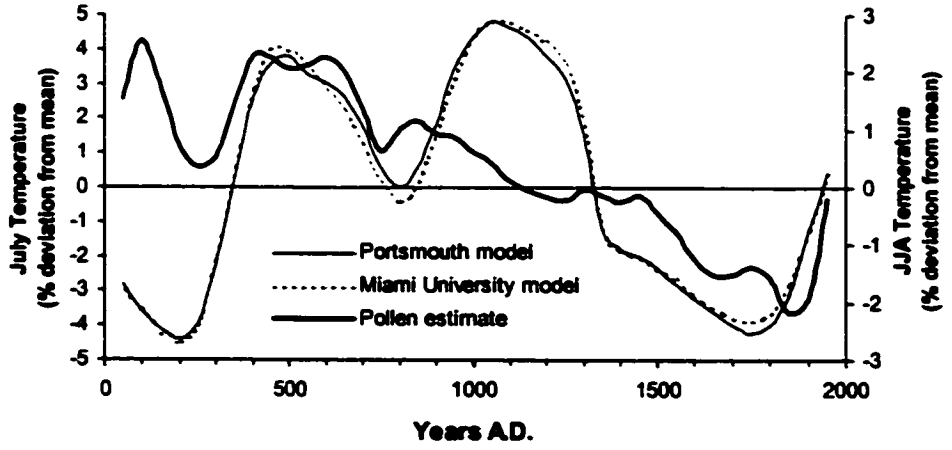


Figure 223. **July temperature, as estimated by macrophysical climatic models for Portsmouth and Miami University, plotted against JJA temperature estimates derived from pollen records.**

temperature models are supported to varying degrees by JJA temperature estimates (Figure 223) based on pollen data and by borehole temperature histories (Figure 224).

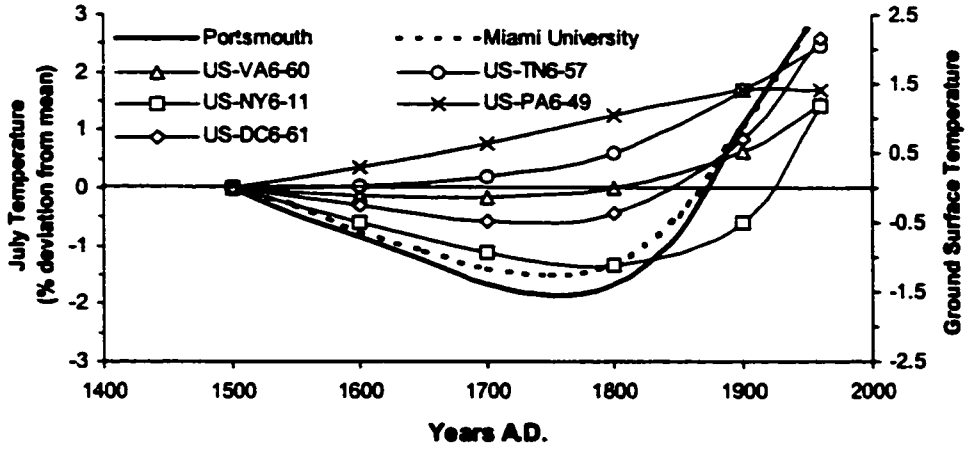


Figure 224. **July temperature history, as estimated by macrophysical climatic models for Portsmouth and Miami University, with ground surface temperature histories (°C) determined from boreholes.**

DERIVING A MODEL OF CLIMATE CHANGE

The goal of this examination of proxy climate data is to develop a model of climatic change that can be arrayed against archaeological evidence for subsistence change. The climatic sequences produced by the independent data sets are marked by similarities and disparities in the timing and direction of climatic change. These sequences will now be melded into a single model of regional climatic change. This model presents a rather simplistic treatment of the proxy climate data, attempting to compress a significant amount of spatial variation into a single regional accounting and emphasizing differences between climatic regimes, as opposed to climatic variation, in the temporal dimension. Resolution of these

problems will require more data and better chronological resolution than available for this analysis.

Figure 225 presents summary graphs that depict the different climatic variables as documented by the different proxy climate data sets. All three variables reflect a combination of the different proxy sources and they are presented as percent deviation from the mean. The summer temperature record, shown at the top, is determined from pollen data and the macrophysical climatic models; the mixed precipitation/temperature record, shown in the middle, is a product of the mesic index, tree ring and beach ridge data; and the annual precipitation record in the bottom plot is determined from the pollen data and the macrophysical climatic models. Figure 226 synthesizes these data into one climatic sequence that is structurally comparable to other climatic models for the study region.

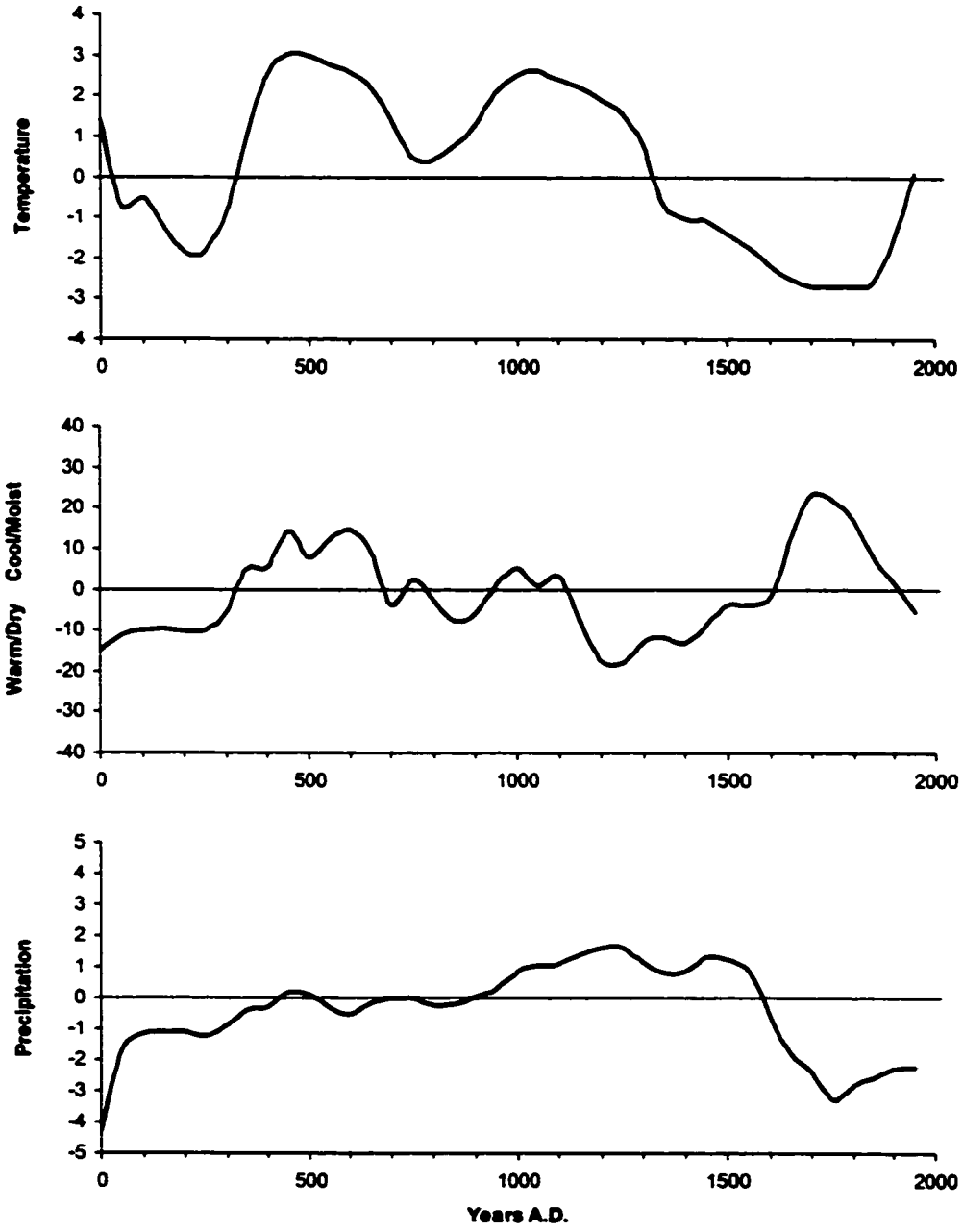


Figure 225. **Summary temperature, mixed temperature and precipitation, and precipitation records.** Data presented as percent deviations from the mean.

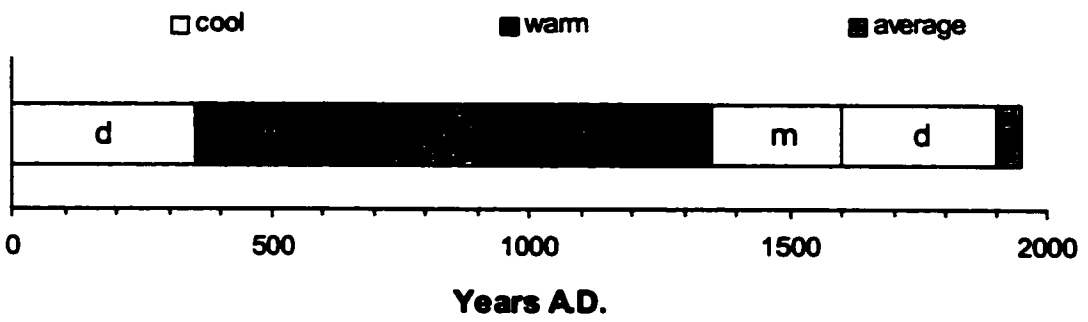


Figure 226. **New model of climatic history for the study region.** Fill color indicates relative summer temperature; letters indicate precipitation with d = dry, m = moist.

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