

Chapter 10

Aging and Sexing Human Remains from the Hopewell Site

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Accurate aging and sexing of individual skeletons is fundamental to bioarchaeological analysis. Without these basic data, a mortuary site is limited in its potential to inform us about social organization, gender roles, the functions of ceremonial artifacts, and the demographic structure of the local community. The need for reliable age and sex information is particularly acute within Ohio Hopewell mound and earthwork sites, because extant collections of the individuals buried at the sites are spotty in coverage, putting a premium on the study of the individuals that are available. Most Ohio Hopewell sites were excavated in the late nineteenth and early twentieth centuries (Chapter 7), prior to the development of modern archaeological methods. Recovery of burial goods and description of mound architecture was of primary concern during this period, whereas the recovery and analysis of skeletons was, at best, of secondary importance. Most early excavators left many skeletons behind, retrieving only the better preserved or more “interesting” specimens they encountered. Among the already limited skeletal samples sent to museums for curation, poor labeling in the field further reduced the number of individuals who could be tied to particular proveniences within a site. Issues such as these have left

bioarchaeologists with a restricted osteological record from which to conduct mortuary analyses of Ohio Hopewell cemeteries.

This chapter continues efforts made in the previous to maximize in the HOPEBIOARCH data base the number of individuals with age and sex information that can be reasonably used in the study of Hopewell social life and the reliability of that information. The chapter focuses on identifying the ages and sexes of individuals exhumed from the Hopewell site, Ohio (Moorehead 1922; Shetrone 1926a). A large number of general methodological issues that are involved in aging and sexing skeletons and that are relevant to human remains from the Hopewell site are reviewed. The review leads to the selection of particular standard aging and sexing techniques and their application to the Hopewell site materials. The review also suggests the usefulness of some less commonly used methods that employ contextualized, population-specific strategies for aging and sex. These methods include seriation of individuals based on select criteria, and the multifactorial methods of discriminant function analysis and principal components analysis. The standard and nonstandard methods are applied to the skeletal series from the Hopewell site

and the resulting ages and sexes of individuals are reported.

In addition to assigning refined ages and sexes to individuals from the Hopewell site, this chapter also provides a very detailed description of each burial from the site, based on laboratory study and a compilation of descriptions and inventories in field notes, publications, and museum records. Each description of an individual, to the extent known, considers whether the skeleton was removed from the field, the parts of the body currently present and missing; the preservation conditions of the remains; whether the remains are cremations, inhumations, or inhumations with charring; body position and orientation in the field; cut marks; locations of copper staining by associated copper artifacts; the pages in field notes and publications that describe and make reference to the individual; and any confusion about the identity of the individual, such as burial and catalog numbers that do not match, or burial numbers for remains that do not match their description in field notes or publications. Confusions are resolved where possible. Also presented is a full list of the human remains excavated by Moorehead and Shetrone, and which remains could and could not be located in the archives of the Field Museum of Natural History and the Ohio Historical Society. The age assigned to each individual in the field, when stated, the age and sex determined by this author for each curated individual, and the suite of methods used to do so, are tabularized. All of this information is presented in Appendices 10.1–10.4. They will be very useful to other researchers who wish to work with the collections of human remains from the Hopewell site.

THE HOPEWELL SITE

Among the many Middle Woodland sites excavated in Ohio during this period, the Hopewell site provides perhaps the greatest potential for bioarchaeological investigation. Rich in grave goods made from exotic materials, it is also the site with the greatest number of excavated individuals for which information is

available by individual (Chapter 7, Table 7.2). The Hopewell site was excavated over a period of 2 years by Moorehead (1891, 1897a, 1922) and then over 4 years by Shetrone (1922–1925, 1926), producing skeletal remains from at least 230 individuals. Shetrone reports encountering 71 individual burials, eight double burials, one triple burial, one bundle burial, and a cache that included human remains. Sixty of these individuals were inhumations, 32 were cremations, and six were partially cremated. Moorehead reports encountering 105 individual burials, 12 double burials, and one triple burial, of which 124 were inhumations, five were cremations, and three were partially cremated. Unfortunately, not all of the individuals from the Hopewell site are available for study. Although 184 inhumations were reportedly excavated, many were not saved. Of those that were collected, only 74 (40%) can be tied to a particular provenience (Appendix 10.1).

IMPROVING AGE AND SEX DATA FROM THE HOPEWELL SITE

Age estimates can be produced for many of the individuals from the Hopewell site using various standard morphological techniques developed from modern populations. However, in order to overcome the error introduced by biological variation in the skeletal aging process, Lovejoy et al. (1997) advocate methods that rely upon an understanding of the biology of skeletal growth, maturation and senescence at the individual level. The goal of such methods is to evaluate the skeletal age of the individual via multiple age indicators considered together and in the context of the individual skeleton and population rather than via individual indicators considered separately and correlated with the chronological age of individuals from another population. Similarly, there are numerous methods, both qualitative and quantitative, by which sex can be determined from human skeletal remains. The degree to which males and females differ for any given trait or measurement varies from population

to population; hence, some means of distinguishing the sexes may perform with greater accuracy in one human group than in another. Sex estimates, like those of age, are best made in the context of the population.

Aging and sexing techniques that involve population-specific analyses can be applied to increase the demographic data available for Hopewell skeletons. The reason that many of these techniques are not commonly used, and have not been used for the Hopewell skeletal series, is that they tend to be time-intensive. They require comparative analysis of a large number of individuals from the same site or area.

Because data on age and sex for the Hopewell site skeletons were not likely to be as reliable when applying only standardized techniques to the available material, some less common methods of aging and sexing are used here with the goal of increasing the amount of reliable information available for the skeletons. This analysis was originally part of a larger study designed to better understand the significance of culturally modified human remains at the Hopewell site by analyzing the age and sex distributions of the remains, themselves, as well as of those individuals buried with the remains (Johnston 2002). Supplementary age and sex information for both projects was obtained by

Table 10.1. Sexing Methods Used in this Study

Method Number	Description	Source
1	Presence/absence of ventral arc: present = F; absent = M	Phenice (1969)
2	Presence/absence of subpubic concavity: present = F; absent = M	Phenice (1969)
3	Breadth of ischiopubic ramus: narrow = F; broad = M	Phenice (1969)
4	Width of greater sciatic notch: 1 = F; 2-5 = M	Buikstra and Ubelaker (1994)
5	Condition of sacroiliac articulation: raised = F; flat = M	Bass (1995)
6	Presence/absence of preauricular sulcus: present = F; absent = M	Buikstra and Ubelaker (1994)
7	Breadth of subpubic angle: broad = F; narrow = M	Bass (1995)
8	Robusticity of supraorbital tori: 1 or 2 = F; 4 or 5 = M	Buikstra and Ubelaker (1994)
9	Robusticity of mastoid process: 1 or 2 = F; 4 or 5 = M	Buikstra and Ubelaker (1994)
10	Robusticity of nuchal crest: 1 or 2 = F; 4 or 5 = M	Buikstra and Ubelaker (1994)
11	Diameter of femoral head: < 43.5 mm = F; > 46.5 mm = M	Bass (1995)
12	Diameter of humeral head: < 43 mm = F; > 47 mm = M	Bass (1995)
13	Seriation of cranial robusticity	See text
14	Discriminant function calculated using dental metrics	See text

Table 10.2. Aging Methods Used in this Study

Method Number	Description	Source
1	Seriation of maxillary dentition	See text
2	Seriation of mandibular dentition	See text
3	Seriation of auricular surface of the ilium	See text
4	Metamorphosis of auricular surface of the ilium	Lovejoy et al. (1985b)
5	Seriation of pubic symphysis	See text
6	Metamorphosis of pubic symphysis	Brooks and Suchey (1990)
7	Degree of ectocranial suture closure	Meindl and Lovejoy (1985)
8	Skeletal maturation (epiphyseal fusion)	Buikstra and Ubelaker (1994)
9	Dental development	Buikstra and Ubelaker (1994)
10	Size or robusticity to distinguish adults and subadults	Personal Experience
11	Diaphyseal length	Ubelaker (1989)
PC	Denotes that age was estimated via principal components analysis of the listed indicators	See text

applying a number of different aging and sexing techniques to the Hopewell sample. In addition to the more standard morphological techniques for sexing the skull and pelvis (e.g., Phenice 1969; Buikstra and Ubelaker 1994; Bass 1995), skulls were also seriated by overall robusticity, and metric sexing techniques were applied to the humerus, femur, and dentition (Table 10.1). Standard aging techniques such as dental development and epiphyseal fusion in subadults, and cranial suture closure, pubic symphysis, and auricular surface morphology in adults, were supplemented with measurements of diaphyseal length in subadults and seriation of dentitions, auricular surfaces, and pubic symphyses in adults (Table 10.2). In addition to these single technique approaches, multifactorial methods were also applied to the sample. Discriminant functions were created from dental measurements as a multifactorial sexing method, and principal components analysis was used as a multifactorial approach to aging skeletal remains.

ISSUES IN AGING AND SEXING SKELETONS

Age Estimation for Adults

Skeletal age is determined by assessing the degree to which a skeleton has grown, matured, or deteriorated at the time of death (Stewart 1979). Because of variations in individual biology and environmental stresses over a person's lifespan, people of the same chronological age will not necessarily exhibit an identical skeletal age. Yet it is chronological age that is of greatest interest to bioarchaeologists. Chronological age is important in demography because it is a measure of the length of time an individual was exposed to various factors that contribute to death (Lovejoy et al. 1997). It is also important in social analyses, where prestige and leadership roles within a community are more likely to be influenced by how *long* a person has lived, than by how *well* a person has aged. However, in order to estimate chronological age, it is necessary to compare the skeletal age of an unknown individual to

the skeletal age of individuals who are known to have lived to a certain age (Lovejoy et al. 1997).

There are numerous methods available for the estimation of skeletal age at death from human remains, and for correlating these estimates with chronological age. These approaches provide estimates of age at death within a statistically defined margin of error. However, each method is only as good as the degree to which skeletal and chronological age are correlated for a particular indicator in the population under study. The degree of correlation is affected by individual variation in biological processes that occur throughout life, and by variation in the skill of the researcher performing the assessment.

Age estimation methods can be organized into two categories: those that measure skeletal or dental deterioration, which are applicable to adults, and those that trace skeletal or dental development, which are applicable to subadults. Methods that apply to adults generally include standardized approaches such as degree and pattern of cranial suture closure, and metamorphosis of the auricular surface of the ilium, the pubic symphysis, and the sternal rib ends (Buikstra and Ubelaker 1994). Although these are the methods that tend to be used by bioarchaeologists working all over the world, all methods may suffer from reduced accuracy when applied to populations other than the one from which they were developed (Masset 1989). This is the case because the resulting ages tend to reflect the age distribution of the populations from which the techniques were derived (Jackes 1992).

Biased adult age standards often result in incorrect assignment of individuals from older age categories into younger categories (Bocquet-Appel and Masset 1982; Konigsberg 1985; Buikstra, et al. 1986; Konigsberg and Frankenberg 1994). Whereas subadult individuals are most likely to be placed into their correct age categories, middle aged or old adults are least likely to be correctly categorized (Aykroyd et al. 1999). This is due to the fact that subadults are in the process of growing and maturing, and these processes leave numerous

skeletal and dental age indicators that are closely spaced in time.

Standards used to estimate the age of adult individuals suffer from several deficiencies. Among these are calibration problems (Konigsberg et al. 1997) and inaccuracies that arise in standards because reference populations do not contain similar and sufficient numbers of individuals from each age category. The latter deficiency often explains the misplacement of older adults into younger adult age categories. For example, in the case of the popular pubic symphysis technique, aging of older adults as younger ones results from the standards for the technique having been derived from a medical examiner's office population that was biased against elderly individuals (Brooks and Suchey 1990).

Another means of estimating age at death in adults is by analysis of dental wear. The occlusal surfaces of teeth tend to wear over the lifespan of an individual at a rate dependent upon the composition of the diet and the hardness of the enamel and dentin of the tooth. Since both composition of diet and quality of tooth enamel tend to vary by population, development of broadly applicable age standards from the dentition is difficult. However, within a given population, the relative degree of wear tends to correlate well with relative differences in age (Miles 1963), providing the basis for dental wear seriation approaches to estimating age at death. The approach requires that enough subadult skeletons be available for a sample that rates of wear can be scaled to chronological time (see below). If this is the case, then it is possible to estimate the age of the remaining individuals by seriating their dentitions based on relative wear. However, it should be kept in mind that confounding factors such as the use of teeth as tools can alter the rate of wear in some individuals.

Because biological variation introduces error into the skeletal aging process, many researchers advocate using a combination of age indicators taken together. Also recommended is considering multiple indicators in the context of the individual skeleton and its population, rather than considering individual

indicators separately and correlated with the chronological age of individuals from another population (Lovejoy et al. 1985a; Mensforth and Lovejoy 1985; Jackes 1992; Lovejoy et al. 1997). Although most summary studies of age estimation techniques recommend using multiple indicators if enough of the skeleton is present (Shipman et al. 1985; Işcan 1989; Ubelaker 1989; Schwartz 1995), very few authorities on the subject contribute methodology for compiling ages derived from multiple approaches into a meaningful estimate of age. An exception is the work of Lovejoy et al. (1985a), who advocate the use of principal components analysis to produce a summary age from the various age ranges derived from multiple indicators on a series of skeletons. The advantage of this approach is that it has been tested and found to produce more accurate and less biased age estimates than ages based on a single indicator (Lovejoy et al. 1985a; Bedford et al. 1993).

Age Estimation for Subadults

Estimation of age based on the skeletal remains of subadults is somewhat less problematic than estimation of age from adult skeletons. Bioarchaeologists have growth and development markers to guide their estimates of skeletal age in the immature, including development of both the skeleton and the dentition. Because dental and skeletal development are not perfectly correlated, each approach can be used to produce an age estimate based on multiple indicators. Dental calcification patterns, dental eruption sequences, and loss of deciduous teeth can all be used to estimate the age at death of subadults. Among these, the loss of deciduous teeth is the least reliable (Hillson 1996) because environmental factors may play a role in the timing of tooth loss. Furthermore, dental eruption is less correlated with chronological age than dental calcification (Smith 1991).

Despite these minor differences in accuracy among the various methods, skeletal age estimates for subadults are generally better than those for adults. Subadult methods are accompanied by smaller margins of error

because the developing skeleton and dentition are marked by so many age-related changes that occur in a predictable sequence. In general, the older the individual, the more skeletal variability should be expected, and the greater the error in estimating age (Krogman and Işcan 1986). It is much easier, for example, to distinguish a 2 year old from a 12 year old than it is to distinguish a 30 year old from a 40 year old.

Error is, however, introduced into subadult age estimates in several ways (Ubelaker 1989). First, variation in the growth rates of children contributes error to estimates. Growth rates are affected by both genetics and overall health, including diet and disease (Krogman and Işcan 1986; Johnston and Zimmer 1989; Saunders 2000). In addition, much of the data used to formulate skeletal age estimation techniques in children were collected using radiographic observations of living children. This is problematic for several reasons. First, many children who are buried in an archaeological site may have died from malnutrition or chronic illness, which could easily have slowed their rate of growth compared to healthy children who were radiographed to create the comparative standards. Second, degree of dental calcification may be underestimated from radiographic observations, and the lightly mineralized bones of subadults tend not to show up as well on radiographs. Since bones and teeth of deceased children tend to be irradiated longer than those of the living, the age resulting from skeletons may appear older relative to the standards than is actually the case. Furthermore, dry bone observations of recently fused epiphyses are more accurate than those from radiographs because the line of fusion remains observable for a period of time on the dry bone, but not in a radiograph. However, Krogman and Işcan (1986) estimate that this last factor only causes age estimates to be off by about 6 months. Other osteological methods have been worked out on archaeological populations for which age at death was estimated from dental events and thus depend on the accuracy with which the dental indicators were derived and the applicability of them to populations other than the one from which they were derived

(Ubelaker 1989). All of these issues argue for the use of multiple methods, where possible, to obtain the most accurate ages for subadults.

Not all methods for aging subadults work equally well at all stages of immaturity. Epiphyseal union is most useful for aging adolescents because this is the period during which such unions take place. The *pattern* of epiphyseal union is very regular and predictable (McKern and Stewart 1957); however the *age* at which union occurs varies by sex and population (White and Folkens 1991). The range of variation in timing of union is large for a single bone, but if a number of bones are used to estimate age, the range can be narrowed to acceptable levels. A problem with age standards based on epiphyseal union is that the mean age of union is often reported without a range of variation. Also, multiple years can elapse between the initiation of union and complete union of an epiphysis, yet the standards may not reflect this delay. Furthermore, not all epiphyses are equally good indicators of age. The best indicators are the epiphysis for the proximal humerus, the medial epicondyle of the humerus, the distal radius, the femoral head, the distal femur, the iliac crest, the medial clavicle, and the sacrum (Ubelaker 1989).

For poorly preserved skeletons with a limited number of bones available for study, diaphyseal length can be used to estimate the age of fetuses, neonates, children, and young adolescents. Once epiphyseal fusion begins, however, diaphysis length is hard to measure. The diaphyseal length approach requires comparison to a standardized population, or to individuals within the population of interest who have been aged by other means. The range of variation in the resulting ages is affected by sex, ancestry, and socioeconomic factors (Ubelaker 1989). Again, results are best when based on estimates from multiple limb bones.

Commonly, if remains have not been carefully excavated and recovered, very young subadults are likely to be under-enumerated. Infant skeletons are easy to miss in the field and are not as likely as more mature skeletons to survive postmortem degradation from taphonomic effects (Walker et al. 1988). In addition,

these remains may be only partially collected if the excavator is unfamiliar with human skeletal biology and the number of small epiphyses and developing teeth to expect in an infant. However, if a skeletal sample contains even one reasonably complete infant skeleton, an assumption of recovery bias may not be warranted.

Cultural practices of the group under study may also result in poor recovery of skeletal remains. Ohio Hopewell individuals, for example, are represented in museum collections almost exclusively by skeletons and cremations from mound or earthwork contexts. We assume that these remains are not necessarily representative of the entire population for two reasons. First, the very young and the very old are seemingly under represented (although certain types of populations—those with a high mortality rate in youth that steadily declines but remains relatively high in the adult and old adult categories—might have the same age structure). Second, it does not seem as though enough individuals are present in Hopewell skeletal collections to account for even small populations over the period of time that various mounds in some of the larger sites were used (see also Prufer 1964a:74). If the entire population is not represented in the sample, paleodemographic analysis of population structure is not possible. Also, care must be taken when making mortuary analyses to take into account the absence of certain ages, sexes, or social groups from the sample.

Sex Estimation Techniques

Sexing methods can be classified by the types of data used to determine sex. Morphological methods are based on visual examination of the size and shape of skeletal structures to distinguish the sexes. Metric methods, on the other hand, rely on size variation in the bones or teeth of males and females to distinguish the sexes. The degree to which males and females differ from each other for any given trait or measurement varies from population to population. Hence, some indicators used to distinguish the sexes may perform with greater accuracy in one human group than in another.

Unlike the situation with age estimation, most bioarchaeologists do not bother attempting to sex children or infants. Current standards for the collection of skeletal data do not recommend sexing techniques for children (Buikstra and Ubelaker 1994). In the case of adolescents, if typical female pelvic indicators are present, then sex can be assigned as female. Adolescent pelves that do not exhibit female morphology should not be concluded to be male. Cranial indicators of sex typically associated with males are indicative of the male sex in an adolescent. Adolescent crania that appear gracile, however, should not be concluded to be female. Finally, femoral and humeral head diameters, if sufficiently large to merit the assignment of the male sex to adults, may be used to assign male sex to adolescents.

There are two broad groupings of sex estimation techniques that apply to adult skeletons: (1) techniques that rely on differences in pelvic dimensions and morphology due to the demands of childbirth on the female pelvis, and (2) skeletal differences in size and robusticity that reflect the fact that human males are usually larger and more heavily muscled than human females (Shipman et al. 1985; Ubelaker 1989; Schwartz 1995).

The most accurate sexing techniques involve skeletal differences in the morphology of the pelvis (e.g., Phenice 1969). Some of these indicators result from the fact that the female pelvic outlet needs to be big enough for a neonate's head to pass through. In order to allow the passage of a neonate, the female pelvis tends to have a wide inlet, a wide greater sciatic notch of the ilium, a long pubic bone, a wide subpubic angle, and an elevated auricular surface. Evidence of parturition in the form of sulci or pits on the dorsal aspect of the pubic symphysis or in the preauricular area is also a female trait. In addition, the structure of the female pelvis is characterized by the presence of a ventral arc, a subpubic concavity, and a narrow, ridged medial aspect of the ischiopubic ramus. The Phenice method (Phenice 1969) involves scoring the pubic bones for these latter three traits (Table 10.1). If all three conditions are present, Phenice (1969) claimed that the method

could be used to assign female sex to a skeleton with close to 100 % accuracy. The presence of the ventral arc is the most highly correlated with female sex of these three indicators.

Sexual dimorphism in size and robusticity is also useful for assigning sex to skeletal elements. In general, females are smaller in size and more gracile than males. Cranial traits that tend to be observable on male crania include prominent supraorbital ridges, heavy temporal and nuchal lines, square orbits with dull superior margins, and large mastoid processes. In addition, males tend to have squarer chins than females, a greater degree of gonial eversion, deeper mandibular rami and more rugose muscle attachment points on the mandible. Postcranial dimorphism between the sexes is reflected in size differences of joint surfaces. Two commonly used postcranial metrics that distinguish males from females are the diameters of the heads of the humerus and femur. For any skeletal dimension, there will be overlap between males and females in the size ranges produced when a large number of individuals are measured. This results in a subset of measurements at the top of the female range, and one at the bottom of the male range, that do not distinguish between males and females. To the extent that the distribution of values of a skeletal or dental metric produces a bimodal distribution, males and females can be distinguished via the calculation of a discriminant function. A discriminant function uses the metrics of groups of known males and females as a basis for comparison of the metric data from an unknown. The discriminant function will classify the unknown as male or female depending on how similar it is metrically to individuals of known sex.

Another means of separating a group of skeletons by sex is to seriate them. Skeletal elements can be arranged according to a qualitative or quantitative trait in order from most masculine to most feminine. The seriation can be anchored by including elements from individuals of known or securely estimated sex. The goal of seriation is to divide a group of skeletons into three subgroups: those most likely male, those most likely female, and those

that are intermediate and therefore indeterminate. Crania can be seriated using traits associated with size and rugosity such as prominence of the supraorbital ridges, nuchal crest, mastoid processes and temporal lines. Seriation avoids the problems of many of the other standardized sexing techniques in that the local population, rather than some unrelated group, is the comparative unit by which sex is assigned to unknowns. However, the process can also be quite time-consuming when working with large samples, which may explain why it is used infrequently in bioarchaeological studies despite certain advantages.

SAMPLES INCLUDED IN THE STUDY

Although the focus of this study is the aging and sexing of individuals interred at the Hopewell earthwork, human remains from seven other neighboring Hopewell sites were included in the project. The additional individuals were considered in order to obtain sufficient subadult skeletons for the dental seriations, to increase the number of aged and sexed skeletons available for use in the skeletal seriations, and to maximize sample sizes generally for statistical purposes. The sites from which the additional individuals were recovered are located within the geographic region defined by the Scioto river drainage from its confluence with the Olentangy river to its confluence with the Ohio river. The sites are: (1) Edwin Harness mound at the Liberty earthwork, (2) Raymond Ater mound, (3) Seip earthwork, (4) Rockhold mound group, (5) West mound (also known as the White mound), (6) Tremper mound, and (7) Bourneville mound. See Chapter 7 for a description of each of these sites. Most of these collections are curated at the Ohio Historical Center in Columbus, Ohio. See Table 10.3 for more information on collection locations and catalog numbers for material from each site.

Age Estimation

Eleven separate methods of age estimation were used in this study (Table 10.2). The methods

Table 10.3. Curation Locations and Catalog Numbers of Sites Having Human Remains and Included in this Study

Collection	Site Number	Location	Catalog Numbers
Bourneville Mounds	33RO46	Ohio Historical Center	A3719
Edwin Harness Mound (Mills)	33RO22	Ohio Historical Center	A7
Edwin Harness Mound (Moorehead) ¹	33RO22	Cleveland Museum of Natural History	13814, 13849, 13851, 13880, 13910, 13911, 13912, 13916, 13929, 13983, 13994, 13997, 13999, 14024, 14074, 14150, 14152, 14153, 14154, 14155, 14156, 14157, 14159, 14161, 14162, 14164, 14166, 14168, 14171, 14177, 14178
Hopewell (Shetrone)	33RO27	Ohio Historical Center	A283
Hopewell (Moorehead) ²	33RO27	Field Museum of Natural History	40455, 40456, 41593–41625, 56068, 56095, 56032, 56064, 56033, 56034
Raymond Ater Mound	33RO63	Ohio Historical Center	A3062
Rockhold Mounds	33RO39	Ohio Historical Center	A1020
Seip Mounds	33RO40	Ohio Historical Center	A957
Tremper Mound	33SC4	Ohio Historical Center	A125
West (White) Mound	33HI13	Ohio Historical Center	A3505

¹Human remains from the Greber excavations are curated under the CMNH numbers 33RO22-72 B&C, 921-A-700C, 921-A-271/a, and 921-A-281/e.

²The Milwaukee Public Museum owns a culturally modified human maxilla fragment that was collected by W.K. Moorehead and transferred from the Field Museum of Natural History to the Milwaukee Public Museum as an exchange in 1945. It is cataloged under the Field Museum number 56034-3 and the Milwaukee Public Museum number A49121/16082.

applied to a particular skeleton depended upon the stage of life (adult or subadult) at the time of death and the completeness and condition of the remains. Data from seven of the 11 aging methods were then used in various combinations to calculate a summary age using principal components analysis, in a manner similar to the multifactorial method proposed by Lovejoy et al. (1985a). Information from only seven methods was used in order to optimize the number of individuals analyzed and the number of age variables considered. The individual aging techniques and the procedure for the principal components analysis are described below.

Dental Seriations

Age at death was estimated via degree of molar attrition using the method of Miles (1963, 1978). In the first step of this process, dental arches recovered from the Hopewell mound group, Edwin Harness mound, Raymond Ater mound, Seip mounds, West mound, and Rockhold mounds were physically arranged in

order from those with the least degree of molar attrition to those with the most severe molar attrition.

Factors that would contribute to differences in rates of wear between individuals interred at various Scioto drainage Hopewell sites, such as differing means of subsistence or oral activity, have not been observed. In addition, the ages produced by the dental seriations correspond well with ages derived from the other age indicators. These two facts suggest that there was not enough genetic or environmental variation between the individuals from different Hopewell sites in the Scioto drainage to alter basic biological processes from group to group. Thus, dental arches from the several Hopewell sites in the Scioto drainage could be combined into one set for seriating. Combining the arches from the sites served two purposes. The first was to maximize the precision of the seriations; a larger seriation will perform better as a tool for estimating ages of unknowns. The second reason for combining individuals was to include as many

developmentally immature arches as possible. This was critical because the numeric age estimates of older individuals are anchored on those of the immature, as described below.

The arches of individuals with immature dental development were assigned a developmental age based on stages of formation of dental crowns, roots, and apices using the scoring system and norms of Moorees et al. (1963b) as reproduced in Ubelaker (1989). Functional ages (length of time teeth had been functional in the mouth) of molars were calculated based on the fact that first molars tend to become functional when the individual is around the age of 6 years (when their functional age is zero), second molars become functional around the age of 12 years (at the same time the first molar will have a functional age of 6 years) and third molars become functional at about 18 years (at the same time that second molars have a functional age of 6 years and first molars have a functional age of 12 years).

Age of the least worn unknowns in the seriation can be estimated through any of three processes. One approach is to identify an individual exhibiting second molar wear that is essentially the same as the degree of wear on the first molar of an individual of known age (based, for example, on epiphyseal fusion or dental eruption). For instance, if an individual of known age was 12 years old, and had first molar wear essentially equal to the second molar wear of an unknown, then the age of the unknown individual could be estimated as 18 years. This calculation is possible because first molars have a functional age 6 years older than second molars; the age of the unknown can be estimated by adding six to the developmental age of the known. Second and similarly, age of unknowns could be estimated by identifying an individual with third molar wear that matches the degree of second molar wear of an arch that had been assigned a developmental age. Again, because second molars have a functional age 6 years older than third molars, the age of the unknown can be estimated by adding six to the developmental age of the known. The third option is to match the degree of third molar wear with the degree of first molar wear of an arch which had been assigned a developmental age. Because

first molars have a functional age 12 years older than third molars, the age of the unknown can be estimated by adding twelve to the developmental age of the known.

The same steps were taken to estimate the ages of arches with higher degrees of wear once ages had been estimated for more lightly worn arches. The lightly worn arches then served as the known individuals as the process continued into older age categories.

In order to avoid reporting misleadingly narrow age estimates for this approach, arches that had been assigned either a developmental or a calculated age were grouped into 5-year age categories. In some cases, an individual had been assigned more than one age because the upper and lower arches were seriated separately. If the two ages did not fall in the same or adjacent 5 year categories, the ages were not used in the principal components analysis.

Auricular Surface of the Ilium

Age was estimated by assigning a chronological stage to each auricular surface as described in Lovejoy et al. (1985b). Stages are defined based on the state of various features of the auricular surface of the ilium and the retroauricular area. Auricular surfaces were also aged by seriation. Auricular surfaces from individuals were arranged in order from most youthful in appearance to least youthful according to descriptions of morphological changes associated with age found in Lovejoy et al. (1985b). The seriated ilia were then separated into groups corresponding to the chronological stages described in Lovejoy et al. (1985b).

Pubic Symphysis

Each pubic symphysis was assigned to a range of chronological ages as described in Brooks and Suchey (1990). If the unknown had been assigned to a sex, series of casts based on pubic symphyses that illustrate the characteristics of each age range for both sexes were used for comparison to help choose the best age range for the unknown. Casts for this purpose were obtained from France Casting. Pubic symphyses were also seriated in a manner similar to that described for seriation of the auricular surface of the ilium.

Ectocranial Suture Closure

Degree of closure of the ectocranial sutures was scored and corresponding age ranges encompassing one standard deviation were calculated as described in Meindl and Lovejoy (1985). In the event that the suture at a particular site could not be scored, an age range was determined using the youngest age that a score of "no closure" at the site would produce (minus one standard deviation) and the oldest age a score of complete closure at the site would produce (plus one standard deviation).

Degree of Union of Centers of Ossification

The degree of union of ossification centers was scored as recommended in Buikstra and Ubelaker (1994). A chronological age range corresponding to the degree of skeletal maturity exhibited by union or lack of union of ossification centers was estimated by referring to published summaries of data found in Krogman and İşcan (1986), Buikstra and Ubelaker (1994), Bass (1995), and Schwartz (1995).

Stage of Formation of the Dental Crown, Root, and Apex

Stages of formation of dental crowns, roots, and apices were scored based on drawings that appear in Buikstra and Ubelaker (1994), which are modeled after information in Moorees et al. (1963a, b). Teeth were also documented individually as to whether they had erupted, were in the process of erupting, or had not erupted. The scoring system of Moorees et al. (1963a, b) was used to document the stage of formation. Age at death was estimated using the norms of Moorees et al. (1963b) as reproduced in Ubelaker (1989) and diagrams illustrating the sequence of formation and eruption that appear in Ubelaker (1989).

Diaphysis Length

Measurements of subadult bones were collected as recommended in Buikstra and Ubelaker (1994), which are based on methods described in Fazekas and Kosa (1978). Correlations between diaphyseal length and chronological

age as diagramed in Ubelaker (1989) were referred to in order to produce an age estimate.

Overall Size and Robusticity

Some sets of remains as well as individual bones were incomplete to the extent that none of the age indicators described above could be used. In such cases, the degree of robusticity or general size was used where possible to distinguish adults from subadults.

Principal Components Analysis

Because more than one aging method could be used on many skeletons in the study sample, and because ages of an individual derived from multiple indicators are highly correlated, a multifactorial method of estimating age via principal components analysis was employed. Principal components analysis allows correlated age indicators to be weighted according to the amount of variation they contribute to an age distribution. The number of principal components produced is equal to the number of variables, with the first component accounting for the greatest variation. This research is modeled after Lovejoy et al. (1985a) who found that the summary age resulting from using more than one age indicator was more accurate and less biased than ages estimated using a single indicator. Bedford et al. (1993) tested the multifactorial method on the skeletons of individuals of known age at death who died during the twentieth Century. Their findings confirmed the assertions of Lovejoy et al. (1985a) that the multifactorial method performs better than any individual indicator for estimating ages of skeletal series.

The number of individuals for whom a summary age could be calculated was maximized by identifying the combinations of age estimation methods that had been applied to the largest numbers of individuals. There were seven such combinations. Seven intercorrelation matrices were compiled from the midpoints of age ranges produced by the following indicators: (1) seriated maxillary dentition and seriated mandibular dentition; (2) seriated mandibular dentition and ectocranial suture closure; (3) seriated maxillary dentition, seriated

mandibular dentition, and ectocranial suture closure; (4) seriated mandibular dentition and seriated auricular surface of the ilium; (5) seriated maxillary dentition and ectocranial suture closure; (6) seriated maxillary dentition, seriated mandibular dentition, and seriated auricular surface of the ilium; and (7) seriated maxillary dentition and seriated auricular surface of the ilium.

Seven principal components analyses were carried out using Number Cruncher Statistical System software (version 2000) to produce a weighting for each indicator in each of the seven analyses. A weighted average of the individual ages was calculated. The correlation between each individual indicator and the first principal component was calculated by multiplying the eigenvector by the square root of the first eigenvalue and then dividing the product by the standard deviation of the *i*th variable. The best estimate of age was calculated by multiplying each individual age by its correlation with the first principal component and dividing by the sum of the correlations (Lovejoy et al., 1985a).

Where more than one combination of individual age indicators was used to age an individual, the best estimate of age was taken to be the one produced by the principal components analysis with the largest eigenvalue for the first eigenvector. The results of the principal components analyses are given in Table 10.4. The ages assigned to individuals are presented in Table 10.5.

Sex Assignment

Fourteen indicators were used to assign sex. The majority are standard indicators described in Buikstra and Ubelaker (1994). They are listed in Table 10.1 along with the scores that indicate maleness or femaleness.

Seriation of Cranial Robusticity

Adult crania of those individuals who had been sexed using pelvic morphology were arranged in groups by sex. The male crania were then arranged in order from least to most gracile and the female crania were arranged in order

from most to least gracile. The seriation was carried out under the assumptions that the Hopewell were sexually dimorphic, that the sexual dimorphism resulted in male crania being more robust than female crania, and that a continuum in robusticity could be produced by arranging the known-sex crania from least to most robust within their respective categories. Some overlap in the two groups was expected, but in general a continuum was produced. Too much overlap would have rendered the seriation of no utility in assigning sex to unknown crania. Crania of unknown sex were then inserted into the seriation where appropriate based on robusticity.

The cranial traits that proved most useful in seriating the Hopewell crania were the supraorbital tori, nuchal crest and mastoid processes. Sex was assigned if an unknown cranium fit securely within the male or female series. Crania that fell in the area of overlap were not assigned sex based on cranial seriation. A similar procedure was attempted using mandibular morphology. However, many of the mandibles of individuals known to be females based on pelvic morphology were very robust. Therefore, useful series of males and females based on mandibular morphology could not be produced.

Sex Assignment by Discriminant Function Analysis

Discriminant function analysis was used to classify individuals of unknown sex into the male or female category using dental metrics as independent variables.

Buccolingual, mesiodistal, crown height, and root length measurements were taken on all teeth where possible and generally following Buikstra and Ubelaker (1994) and Goose (1963). One hundred individuals with complete or nearly complete dentitions were included in the analysis. Of these, 54 had been assigned to a sex category via cranial or pelvic morphology ($n = 22$ males; $n = 32$ females) and 46 were of unknown sex. The majority of the individuals included in the discriminant analysis were from the Hopewell mound group, but several sexed

Table 10.4. Principal Components Analyses Results

ID Number	Mound/ Burial	Age 1	Age 2	Age 3	Age 7	PCA 1	PCA 2	PCA 3	PCA 4	PCA 5	PCA 6	PCA 7	Best Estimate	Range
150108	2/1	33	38	37	48	36	42	38	38	39	35	34	36	30-40
150109	2/3	18	23	37	-	21	-	-	21	-	19	23	21	20-25
150112	2/4	18	23	32	33	21	27	23	22	24	19	22	21	20-25
150215	2/5	33	48	-	43	41	46	41	-	37	-	-	41	35-45
150129	4/3	23	38	37	-	31	-	-	38	-	30	27	31	25-35
150143	4/4	43	43	37	42	43	43	43	44	43	44	41	43	35-45
150127	4/9	-	53	37	46	-	50	-	55	-	-	-	50	45-55
150137	7/1	23	-	37	35	-	-	-	-	28	-	27	28	25-35
150138	7/3	23	23	-	43	23	30	27	-	31	-	-	23	20-30
41618	18/181	38	48	-	-	43	-	-	-	-	-	-	43	40-50
41602A	23/198	18	31	-	46	25	36	29	-	29	-	-	25	20-30
41598A	23/198	18	23	-	42	21	30	25	-	27	-	-	21	20-25
41613	23/205	23	28	-	-	26	-	-	-	-	-	-	26	20-30
41606	23/228	18	28	-	-	23	-	-	-	-	-	-	23	20-30
56068	24/192	18	18	-	-	18	-	-	-	-	-	-	18	15-20
150165	25/6	23	27	37	44	25	33	29	26	31	24	27	25	20-30
150166	25/7	18	23	42	41	21	30	25	21	27	18	25	21	20-30
150213	25/11	23	28	-	-	26	-	-	-	-	-	-	26	20-30
150124	25/12	23	33	-	36	28	34	30	-	28	-	-	28	25-35
150131	25/15	23	28	37	36	26	31	28	27	28	24	27	26	20-30
150132	25/15	23	28	37	31	26	29	27	27	26	24	27	26	20-30
150122	25/16	18	23	-	47	21	32	26	-	29	-	-	21	20-30
150061	25/22A	33	48	-	44	41	47	41	-	37	-	-	41	35-45
150062	25/22B	23	33	32	32	28	33	29	33	26	28	26	28	25-35
150210	25/23N	43	-	-	42	-	-	-	-	43	-	-	43	40-50
150209	25/23S	43	53	-	48	48	51	48	-	45	-	-	48	45-55
150128	25/24	33	53	27	48	43	51	44	56	39	45	31	43	40-50
150121	25/25	28	33	-	36	31	34	32	-	31	-	-	31	25-35
150117	25/34	-	53	37	46	-	50	-	55	-	-	-	50	45-55
150118	25/34	38	-	-	49	-	-	-	-	42	-	-	42	35-45
150212	25/35	33	43	42	47	38	44	40	43	38	38	36	38	35-45
150056	25/41	23	38	-	39	31	38	32	-	29	-	-	31	25-35

(Continued)

Table 10.4. (continued)

ID Number	Mound/ Burial	Age 1	Age 2	Age 3	Age 7	PCA 1	PCA 2	PCA 3	PCA 4	PCA 5	PCA 6	PCA 7	Best Estimate	Range
150172	25/41	18	18	-	-	18	-	-	-	-	-	-	18	15-20
150053	25/41-2	23	48	-	47	36	48	38	-	32	-	-	36	30-40
150057	25/41-3	38	53	-	39	46	48	44	-	38	-	-	43	40-50
150116	25/42	23	33	37	32	28	33	29	32	26	27	27	28	25-35
150115	25/45	33	43	32	38	38	41	38	44	35	39	33	38	35-45
150164	26/6	33	43	37	48	38	45	40	44	39	38	34	38	35-45
150107	27/1	28	33	27	35	31	34	31	34	31	31	28	31	25-35

Age 1: Midpoint of age range produced by seriation of the maxillary dentition.

Age 2: Midpoint of age range produced by seriation of the mandibular dentition.

Age 3: Midpoint of age range produced by seriation of the auricular surface of the ilium.

Age 7: Midpoint of age range produced by degree of ectocranial suture closure.

PCA 1: Principal components analysis based on midpoint of ranges produced by age methods 1 and 2. First principal component accounts for 94% of the variation in age estimates.

PCA 2: Principal components analysis based on midpoint of ranges produced by age methods 2 and 7. First principal component accounts for 85% of the variation in age estimates.

PCA 3: Principal components analysis based on midpoint of ranges produced by age methods 1, 2, and 7. First principal component accounts for 80% of the variation in age estimates.

PCA 4: Principal components analysis based on midpoint of ranges produced by age methods 2 and 3. First principal component accounts for 77% of the variation in age estimates.

PCA 5: Principal components analysis based on midpoint of ranges produced by age methods 2 and 7. First principal component accounts for 77% of the variation in age estimates.

PCA 6: Principal components analysis based on midpoint of ranges produced by age methods 1, 2, and 3. First principal component accounts for 70% of the variation in age estimates.

PCA 7: Principal components analysis based on midpoint of ranges produced by age methods 1 and 3. First principal component accounts for 57% of the variation in age estimates.

Table 10.5. Aged and Sexed Skeletons from the Hopewell Site, by Provenience

ID Number	Mound	Burial	Age (years)	Aging methods ¹	Sex	Sexing Methods ²
150108	2	1	30–40	PC (1,2)	M	2, 3, 5, 6, 7, 8, 10
150168	2	2	14–19	8	M	11, 12
150109	2	3	20–25	PC (1,2)	F	4, 5, 6, 8, 9, 11,12,13
150112	2	4	20–25	PC (1,2)	F	4, 6, 8, 11, 12
150215	2	5	35–45	PC (1,2)	M	8, 13
150135	4	2 (Skull 1)	Adult	7	F	8, 9
150134	4	2 (Mandible)	50+	2		
150133	4	2	20–35	3, 4		
150129	4	3	25–35	PC (1,2)	M	1, 4, 5, 6, 7, 8, 11
150143	4	4	40–45	PC (1,2)		
150127	4	9	45–55	PC (2,7)	M	4, 5, 6, 8
150137	7	1	25–35	PC (1,7)	F	1–10
150138	7	3	20–30	PC (1,2)	M	14 (F _{app} = 1.04)
41618	18	181	40–50	PC (1,2)	M	8, 9, 11, 13
41617	20	177	30–40	1		
41613	23	205	20–30	PC (1,2)		
41606	23	228	20–30	PC (1,2)	F	8, 9, 13
41608	23	234	40–50	2	F	13
41607	23	236	30–60	7	F	9, 13
150165	25	6	20–30	PC (1,2)	M	1–7, 9–11, 13
150166	25	7	20–30	PC (1,2)	F	1, 4, 6, 8, 9, 11, 13
150123	25	10	36–40	1		
150213	25	11	20–30	PC (1,2)	M	13
150124	25	12	25–35	PC (1,2)	F	8, 14 (F _{app} = 1.04)
150119	25	13			F	8, 9
150132	25	15	20–30	PC (1,2)	F	4, 6, 8, 9, 11
150131	25	15	20–30	PC (1,2)	F	4, 8, 9, 10, 13
150122	25	16	20–30	PC (1,2)	F	8, 10
150061	25	22A	35–45	PC (1,2)	M	1, 3, 6–9
150062	25	22B	25–35	PC (1,2)	F	3–6, 8, 9, 10, 11
150210	25	23N	40–50	PC (1,7)	F	8, 9, 10, 14 (F _{app} = 0.91)
150209	25	23S	45–55	PC (1,2)	M	10, 13
150128	25	24	40–50	PC (1,2)	M	4, 5, 8, 9
150121	25	25	30–35	PC (1,2)	M	4, 6, 8
150117	25	34	45–55	PC (2,7)	M	14 (F _{app} = 0.42)
150212	25	35	35–45	PC (1,2)	M	4, 8, 10
150058	25	41–1	41–45	2	F	14 (F _{app} = 0.91)
150057	25	41–3	40–50	PC (1,2)	F	4, 9, 10, 11
150053	25	41–2	30–40	PC (1,2)	F	8, 9, 10, 11
150116	25	42	25–35	PC (1,2)	F	4, 6, 8, 9, 10
150115	25	45	35–45	PC (1,2)	M	1, 3, 4, 5, 8, 10
150170	26	5			M	11, 12
150164	26	6	35–45	PC (1,2)	M	1–5, 7, 11–13
150107	27	1	30–35	PC (1,2)	F	14 (F _{app} = 0.94)

¹Aging methods correspond to numbers 1–11 and PC in Table 10.2.

²Sexing methods correspond to numbers 1–14 in Table 10.1.

individuals from Seip, Harness, Rockhold, and Raymond Ater were included as well.

The discriminant analysis was performed using NCSS 2000 software. In order to minimize missing values among the independent variables, the data were transformed such that the measurements of antimeres were averaged. In the event that the measurement of one antimeres was missing, the measurement that was present was used regardless of side. Sample sizes of the transformed independent variables ranged from $n = 3$ to $n = 26$. Each independent variable was tested for normality using the Kolmogorov-Smirnov test (critical value = 0.05) and normality was accepted for 132 of the 140 variables. In order to test the assumption that group covariance matrices were equal, Box's M test (Box, 1949 as described in Hintze, 1998) was applied. Probability levels for Box's M (F_{Prob}) ranged from 0.05 to 0.97. Results of the test for each unknown that was eventually successfully allocated to a sex category are reported in Appendix 10.2.

For each individual of unknown sex, discriminant functions were calculated using combinations of independent variables from the knowns. The set of functions that produced the least amount of classification error of knowns was chosen for use in allocating an unknown to a sex category. Descriptive statistics, results of the test for equality of covariances, the linear discriminant functions, and allocation error are reported in Appendix 10.2. The assignments of sex to individuals is reported in Table 10.5.

RESULTS

Detailed descriptions of each of the 230 individuals excavated from the Hopewell site by Moorehead (1891, 1897, 1922) and Shetrone (1922–1925, 1926) are provided in Appendices 10.3 and 10.4. These appendices summarize what is currently known about each of the human skeletons encountered at the Hopewell site, including information about whether the skeleton was collected in the

field; which bones are currently curated in various collections; whether the remains are cremations, inhumations, or inhumations with charring; body position and orientation in the field; taphonomic information such as preservation, presence of cutmarks, and locations of copper staining; pages in field notes and publications that describe or mention the individual; confusion, if any, whether the skeleton with the assigned catalog number is indeed the one described in site field notes and publications; and the most comprehensive age and sex estimates produced to date. Also included are detailed descriptions of culturally modified human remains from the site. The age and sex information for all cataloged and provenienced human remains from the Hopewell site is summarized in Appendix 10.1.

Age and sex determinations for the Hopewell site individuals that could be tied to a particular provenience and were able to be assigned to an age category other than adult/subadult, as well as the techniques used to obtain them, are summarized in Table 10.5. Of these individuals, 42 could be assigned to an age category using the various techniques described above. This result brings the number of inhumations from the Hopewell site with good age estimates to nearly 23%. Six of these new ages resulted from application of additional methods used individually, while 33 ages were obtained by means of principle components analysis, either by combining two of the additional methods, or by combining one of these additional methods with one of the standardized methods. Twelve sexes were determined using seriation of cranial robusticity and 14 sexes were determined using discriminant functions of dental metrics, bringing the total to 38 individuals with reliable sexes and raising the number of inhumations from the site with good sex estimates to nearly 21%. Furthermore, ten of the sexes determined from seriation of cranial robusticity and two of the sexes determined using discriminant functions of dental metrics were supported by individual cranial and postcranial sex indicators, improving the reliability of these estimates for bioarchaeological analysis.

The Scioto Hopewell *and Their Neighbors*

Bioarchaeological Documentation and Cultural Understanding

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Cover Design Acknowledgment: Digital painting, “On the Way”, by Christopher Carr, based on portraits of three ceremonial leaders rendered on three copper celts by anonymous Ohio Hopewell artists, compositions of processions of persons rendered on copper breastplates by anonymous Ohio Hopewell artists, and an early photograph of a virgin hardwood forest in the Allegheny Plateau province of Ohio. The three celts bearing the portraits of leaders, from left to right, are: Carr no. C023 Side A, from the Hopewell earthwork, possibly Mound 25, Skeletons 260–261, curated at the Ohio Historical Society, cat. no. 283/351B; Carr no. C301 Side A, from the Edwards Mound Group, 33HA7, curated at the Harvard Peabody Museum, cat. no. 84-6-10/32346; and Carr no. C011 Side A, from the Seip earthwork, curated at the Ohio Historical Society, cat. no. 957/-. Example depictions of processions of ceremonial leaders are found on breastplates Carr B061 Side B, from the Liberty earthwork, curated at the Ohio Historical Society, cat. nos. 7/1.007 and 13716; and Carr B025 Side A, from the Hopewell earthwork, Mound 25, Burial 6, curated at the Ohio Historical Society, cat. no. 283/83C. The portraits and processions were revealed by color and near-infrared digital photography, hybrid color-near-infrared image display, and image contrast enhancement. The full forest photograph is published by Gordon (1969:Frontispiece). Top and bottom border designs are, respectively, a snake-skin design incised on the top of a pottery vessel and a rocker-stamped bird feather design placed on the body of the same vessel, from the Hopewell earthwork, Mound 25, Altar 1 (Moorehead 1922:171, Figure 70). Cover layout by Christopher Carr and Deann Gates.

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Data Base of Intrasite Layouts

Christopher Carr and Rebekah A. Zinser

Regional Geographic Data Base

Christopher Carr and Rebekah A. Zinser

Ethnohistorical Data Base

Christopher Carr, Rex Weeks, and Mark Bahti

Figures

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Other Appendices

Christopher Carr, D. Troy Case, Beau J. Goldstein, and Cheryl A. Johnston

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