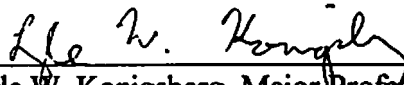


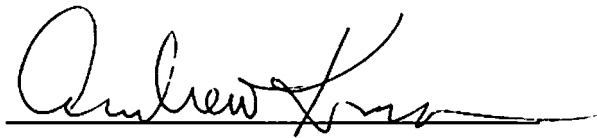
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I am submitting herewith a dissertation written by Ashley H. McKeown entitled "Investigating Variation among Arikara Crania Using Geometric Morphometry." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Anthropology.

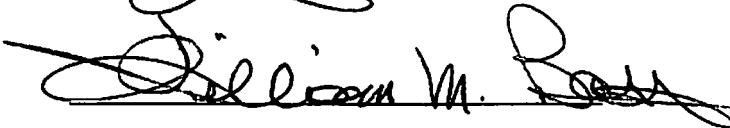


Lyle W. Konigsberg, Major Professor

We have read this dissertation
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Associate Vice Chancellor and
Dean of The Graduate School

**Investigating Variation among Arikara Crania
Using Geometric Morphometry**

**A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville**

**Ashley H. McKeown
December 2000**

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DEDICATION

I wish to dedicate this dissertation to my husband,
Todd M. Ahlman,
who has been my cornerstone of support and encouragement,
and to my parents,
Patrick and Carolyn McKeown,
who raised me to believe I could accomplish any goal that I set for myself.

I would also like to remember the men and women who once lived along the banks of the
Missouri River in South Dakota. You are not forgotten.

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The data collection, data management and analysis phases of this research were made much less complicated by the programming efforts of Drs. Lyle Konigsberg, Richard Jantz, Patrick McKeown and Stephen Ousley. I am indebted to each of them for their contributions and assistance.

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ABSTRACT

Geometric morphometry has seen minimal application in studies of biological variability among subpopulations of humans. However, as landmark coordinates are highly effective for capturing information regarding size and shape variation, the tools of geometric morphometry are appropriate for investigating such questions. This research utilizes landmark coordinate data to quantify morphological variation among Arikara crania to evaluate the biological relationships between skeletal samples from late prehistoric, protohistoric and historic sites. These samples are derived from well documented archaeological contexts, and the presence of biological variability among them has been reported in previous studies. These factors make these samples appropriate for assessing the utility of geometric morphometry for investigating variation among subpopulations separated by time and space.

Forty cranial landmarks were recorded by three-dimensional coordinates on crania from 18 components from Extended and Post-contact Variants of the Coalescent Tradition of the Middle Missouri Region in the Great Plains. The coordinates were fitted employing general Procrustes analysis and the residuals from this procedure were subjected to traditional statistical analyses. Additionally, consensus configurations were employed to generate thin-plate spline transformation plots and comparative plots of Procrustes means depicting the morphological variation present among the various samples. This variation was interpreted in light of the results from analyses of the residuals and the known temporal, geographical and cultural contexts.

Canonical analysis and multiple matrix correlation (Mantel) tests indicate that geographic distance was the primary factor structuring morphological variation among the samples. Additionally, a statistically insignificant temporal trend is observed in the morphological variation across the samples.

This research demonstrates the utility of coordinate data for investigating biological variability and the relationships among human subpopulations based on cranial morphology. By retaining the geometric relationships among the coordinates, the geometric morphometric analyses of the configurations provide information about shape variation among all of the landmarks. While the nature of the variation detected in this study is similar to previous studies, the coordinate data permits the graphical representation of morphological patterns that allows for an appreciation of differences in landmark locations between configurations and a better understanding of morphological variation among these samples.

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CHAPTER 1

INTRODUCTION

Biological variability among subdivisions of human populations is a question of much interest in anthropology. Measuring and evaluating such variability has been central to numerous studies and continues to be addressed with new methodological approaches and interpretative models. Geometric morphometry provides the tools for effectively analyzing landmark coordinate data recorded from biological forms. By employing landmark based data, these new methods utilize all of the size and shape information encoded in the two and three dimensional coordinates for more powerful analyses of shape variation and change. As such, these approaches provide a new arena for investigating biological variability measured from the phenotype.

Much research into biological variability has focused on metric or non-metric cranial morphology. In simple terms, this approach is based on the idea that if morphology is at least in part a reflection of the genotype, then similarities or differences in morphological patterns between and within groups should correspond to similarities or differences in the genetic structure of the populations under consideration. Theoretical advances have enhanced our understanding of how the genetic relationships among populations correspond to the observed morphological patterns. It is now time to look to new methodological approaches that permit greater appreciation of the morphological patterns that exist so that we may better understand the genetic relationships that are present. Towards this end, the current research applies a new methodology for data

collection and analysis to a series of crania from a Native American tribe of the Great Plains. This series has been the focus of extensive investigation into the biological variability that is present among subpopulations which crosscut time and space. This question is readdressed employing three dimensional landmark coordinates and a combination of geometric morphometric tools and more traditional statistical analyses.

The Great Plains has long been of interest to archaeologists and physical anthropologists alike as both sought to understand the prehistory of the populations that were encountered during historic times. Researchers soon began to understand that the Native populations written about by Euro-American fur traders and explorers had already been significantly impacted by direct and indirect contact with Euro-Americans which further spurred interest in the prehistoric populations of the region. Exploratory archaeology of the late 19th and early 20th century gave way to federally mandated salvage projects that preceded the inundation of portions of the Missouri River in South Dakota. These projects increased knowledge regarding the prehistoric populations that had inhabited the region and under the auspices of physical anthropologists, large skeletal collections were recovered and conserved. These collections offered an opportunity to learn about the biological aspects of peoples known from their material culture and augmented interpretations of inter-site relationships. This helped refine the archaeological models for population movements and interactions for the prehistoric and protohistoric periods.

A group that has been of particular interest due to the existence of large skeletal collections from relatively well defined archaeological contexts is the Arikara. Known

historically from the Leavenworth site, which was visited by a number of Euro-American explorers and traders including Lewis and Clark in 1804, the Arikara are thought to have once inhabited villages along the entire stretch of the Missouri River in South Dakota. However, the Arikara were not the only group thought to have resided on the banks of the Missouri in this region. Many of the village sites occupied by the Arikara appear to have been previously inhabited by the Siouan speaking Mandan who were pushed into North Dakota by a northward invasion of the Caddoan speaking Arikara. Therefore, questions regarding the affiliation of skeletal samples, relationships among the subdivisions of the Arikara tribe that are separated by time and geography, their relationships with other tribes from the region and the effects of Euro-American contact have been addressed by traditional morphometric studies of cranial morphology.

In an attempt to readdress some of these questions, the tools of geometric morphometry are used to quantify and interpret the morphological variability present among the samples attributed to the Arikara. Craniofacial landmarks are recorded as three-dimensional coordinates and analyzed using a combination of geometric morphometric methods and traditional multivariate statistical analyses. An important quality of geometric morphometry is the removal of absolute size producing variables that contain only information about shape variation. Size differences can be measured utilizing centroid size, an important parameter for landmark based statistics. Thin-plate spline analysis has the added advantage of partitioning affine (uniform) and non-affine (local) shape change. These approaches provide statistical and graphic tools for interpreting shape variation between forms which should provide a greater understanding

of the nature of morphological variability present. The better we understand the morphological differences that are driving our statistical analyses, the better able we are to interpret the results and propose testable hypotheses regarding the evolutionary factors affecting the morphological variability.

The ensuing chapters provide background information about the new tools of geometric morphometry, the sample employed in this research as well as describing the specific methods utilized and the results of this study. Chapter 2 provides an introduction to the methods associated with geometric morphometry and discusses several pertinent studies of shape variation using these approaches. The archaeological framework of the Middle Missouri Region, Arikara culture history and relevant studies regarding biological variability among Arikara skeletal samples are presented in Chapter 3. A description of the skeletal samples, their archaeological contexts and the landmarks employed in this study are provided in Chapter 4. Chapter 5 discusses the various analytical methods utilized to investigate biological variability based on shape differences in cranial morphology. Chapter 6 presents the results derived from the analytical procedures and Chapter 7 synthesizes the information regarding population relationships and morphological variation among the samples. These relationships and patterns of morphological variability are interpreted in light of relevant research and conclusions are drawn regarding the utility of coordinate landmark data for such research.

CHAPTER 2

GEOMETRIC MORPHOMETRY

As Bookstein (1982:451) observes, morphometry is the fusion of biology and geometry. Stated another way, morphometry utilizes the geometric form to investigate biological change. Traditional morphometrics employs linear distances and angles to quantify differences among biological forms for the purposes of interpreting these differences in light of biological relationships and processes. The new or geometric morphometry uses two or three dimensional landmark data to capture size and shape information from the biological form under investigation. The use of homologous landmarks permits the investigation of size and shape variation based on morphological features that contain biological information regarding the same structure or function across all specimens. A primary focus of geometric morphometry is shape variation, which reflects the properties of the coordinates that are invariant with reference to scale (size), location and orientation (Marcus and Corti 1996:1).

The advantages of landmark data are manifold. A form recorded in two or three dimensional coordinates is permanently archived with information about size, shape and the geometric relationships among all the landmarks preserved. The reconstruction of a two or three dimensional form is simply not possible from the traditional set of interlandmark distances. Additionally, all possible interlandmark distances can be derived from a coordinate data set; however, the reverse is not true for the typical metric data set. Since forms can be reconstructed based on the coordinate data, shape variation

can be visualized in plots that depict those aspects of the organism as represented by the landmark coordinates which are involved in shape change (Marcus and Corti 1996). Previously researchers had to assess columns of numbers to identify metric units that corresponded to changes in morphology and interpret that variation. Regions experiencing changes in proportion relative to one another might not appear as coherent units of information in traditional multivariate analyses; whereas, landmark based plots allow for the simultaneous appreciation of the relative contribution of every landmark to overall and local variation in the form. Last, but certainly not least, is the utility of coordinate data for multivariate analyses. Removing differences due to absolute size, location and orientation produces data sets containing information regarding shape variation that can be submitted to traditional multivariate statistical analyses such as principal component, factor or canonical variates analyses (Marcus and Corti 1996). Since these landmarks contain shape information in two or three directions depending on the dimensionality of the original data set, variation that exists in all available directions can be utilized and investigated. The preservation of geometric relationships among the landmarks retains important shape information that can be lost in traditional linear distances and angles and permits the detection of variation in unexpected directions. With more information regarding shape variation available, statistical analyses should be more powerful for detecting differences in shape (Rohlf and Marcus 1993). It should be noted that the removal of size does not mean that size differences cannot be evaluated. The metric, centroid size which is the square root of the sum of squared distances for a set

of landmarks relative to their centroid (Slice et al. n.d.), retains a measure of absolute size that can be used as a variable for statistical analysis.

In the 1990s, geometric morphometry really hit its stride as technology for data collection and the management and analysis of enormous data sets became increasingly accessible. Application of the methods finally started to catch up to the preceding statistical and theoretical developments that had begun in earnest in the late 1970's but actually have roots extending back to the turn of the 20th century.

Approaches

Many approaches to the analysis of landmark data have been proposed. Currently, four main types of landmark data analysis are considered in discussions of geometric morphometry. Procrustes (or superimposition) methods permit the optimal rotational fitting of two or more configurations. These approaches can be used independently to investigate shape variation or can be used as a initial step for other analyses. Thin-plate spline (TPS) analysis is a component of relative warp analysis that uses a smooth transformation function to deform one configuration into the space occupied by another configuration. This interpolation allows for shape differences to be visualized in terms of a Cartesian transformation grid and it partitions the shape difference into its affine (uniform, overall) and non-affine (local) constituents (Rohlf 1996). One of the earliest approaches of geometric morphometry to see application in anthropology is finite element scaling analysis (FESA) which uses landmarks to generate triangles or tetrahedra that encompass the form under investigation. Differences among these units are computed as

the affine transformations that are required for mapping one unit onto another unit (Rholf and Marcus 1993). Choice in the units employed can affect the detection of overall shape change and this approach has largely fallen out of use in favor of TPS and relative warp analyses. The fourth type of geometric morphometry is Euclidean distance matrix analysis (EDMA). This approach calculates all possible interlandmark distances (ILDs) for a configuration and compares these sets of ILDs across specimens by virtue of ratios (Lele and Richtsmeier 1991, Lele 1993). These approaches are discussed in greater detail below.

Procrustes analysis

Superimposition methods have their roots in the mathematical modeling of Franz Boas at the turn of the century (Cole 1996). In 1905, Boas introduced a method of least differences for superimposing two dimensional configurations. This article provides the mathematical basis for translating the configurations to a common center removing differences in location, rotating the landmarks such that they are oriented with one another and for fitting the configurations by minimizing the sum of the squared distances across all points. Phelps (1932) compared this method to registration systems such as the Frankfurt and French planes and found that Boas' (1905) method was preferable for metrically expressing the differences in morphological types. Her research employing Peruvian, Australian and Eskimo crania determined that the baseline dependent registration systems tended to unequally weight variability in different regions of the skull. The variation that would be present at the baseline registration landmarks, which is assumed not to exist by the registration system, is dispersed to other aspects of the cranial

morphology. Of the methods compared by Phelps (1932) the landmark specific variation was least for Boas' (1905) method of superimposition.

Another early researcher interested in form change for biological organisms was D'Arcy Thompson, who in his 1917 work *On Growth and Form* presented Cartesian transformation grids that depict the hypothetical change in morphological form that would be produced by stretching or compressing parts of the grid system. While Thompson's (1917) grids are visually appealing, there is no statistical foundation to the deformations and, therefore, they have no application to actual studies of shape change. Sneath (1967) introduced a method for quantifying Thompson's grids via trend surface analysis for the purpose of investigating size and shape differences. The approach includes an initial fitting that involves scaling and minimization of a least squares criterion for coordinate based configurations. Gower (1975) formalized the least squares algorithm for a Generalized Procrustes Analysis (GPA) that involves simultaneously translating, rotating, reflecting and scaling configurations so as to minimize the sum of the squared distances across homologous landmarks. Scaling serves to remove size differences between the configurations and the remaining variation across homologous landmarks measures the shape variation. However, minimizing the sum of the squared distances among landmarks tends to spread the variation across the entire configuration with the implication being that all landmarks are contributing equally to the lack of fit (Richtsmeier et al. 1992). Recognizing this shortcoming, Siegel and Benson (1982) developed a resistant-fit for Procrustes analysis that uses a repeated median resistant-fit algorithm for accommodating differences due to non-affine variation. For cases where

small scale differences comprise the majority of the variation across configurations, the resistant fit procedure generally provides a better fit. This method is extended by Rohlf and Slice (1990) to the optimal superimposition of multiple configurations with a generalization for both the least squares and resistant-fit methods that permits uniform shape change. Goodall and Bose (1987) introduced a multivariate Procrustes statistic to test for differences between configurations with the assumption of a Gaussian distribution for the residuals. Goodall (1991) derived F ratio and Hotelling's T^2 tests based on the distribution of the Procrustes statistics developed by Goodall and Bose (1987) for the purpose of assessing the significance of shape differences between configurations. This Procrustes distance is calculated as "the square root of the sum of squared differences between the positions of the landmarks in two optimally (by least-squares) superimposed configurations at centroid size" (Slice et al. n.d.).

Some points regarding Procrustes terminology should be made at this time. Ordinary Procrustes analysis involves fitting one configuration to another; General Procrustes analysis refers to fitting multiple configurations to a consensus. Full Procrustes analysis uses translation, rotation and scaling to achieve the fit; partial Procrustes only involves translation and rotation. For most research into shape differences among multiple specimens General (full) Procrustes analysis is employed.

Thin-plate spline analysis

Borrowing the concept from continuum mechanics, Bookstein (1989) introduced the thin-plate spline (TPS) and relative warp analysis as a quantification of Thompson's Cartesian transformation (1917) grids that accounts for both affine (uniform) and non-

affine (local) change. In continuum mechanics, the thin-plate spline is actually a thin sheet of metal that can be deformed by constraining the location of certain landmarks while permitting other areas to change as needed. This produces a warping of the spline as it forced to take on the new form. Of course, in this application there are no real sheets of metal, but the same concept applies. The space occupied by one configuration is interpolated into the space of another configuration by mapping the landmarks of the first (reference) configuration onto the second (target) configuration.

The initial step in a thin-plate spline transformation is the superposition of the two configurations such that location, orientation and absolute size differences are eliminated. Bookstein (1986, 1991) proposes the use of shape coordinates for this purpose. This approach requires the choice of two baseline landmarks and all other coordinate locations are recalculated relative to the newly defined baseline. Bookstein (1991) maintains that if the shape differences are not too great among the configurations then the shape coordinates contain all the shape information that a set of linear measurements and angle based on the landmarks would possess. As long as the differences among the configurations are not excessive and the variation for each landmark across the forms is patterned in a circular manner, then the statistics of the newly computed shape coordinates are baseline-independent (Yaroch 1996) and useful for further analysis such as thin-plate spline. The removal of location, orientation and scaling differences can also be accomplished by full Procrustes analysis.

The shape change is measured by the bending energy required to achieve the thin-plate spline transformation (Rohlf 1996). Small scale changes require greater bending

energy than large scale changes so interpretation of this parameter is not immediately obvious. The bending energy can also be decomposed into its affine and non-affine components permitting a better understanding of the nature of the shape change occurring. The non-affine components can be further partitioned into partial warps that can then be used in subsequent relative warp analysis (Rohlf 1993, 1996). Partial warps can also be depicted as vectors showing the direction and relative magnitude of the change required by the smooth thin-plate spline transformation.

Finite-element Scaling Analysis

Finite-element scaling analysis (FESA) uses finite elements created by interconnected landmarks to form triangles or tetrahedrons to model the strain necessary to produce a target form from a reference form (Cheverud et al. 1983). Element by element, entire configurations are mapped onto one another and the strain required by the deformation is measured. This produces information about size differences and the magnitude and pattern of shape differences. Since size and shape are the components of form, FESA models form change across all finite-elements for a set of configurations. FESA has fallen out of favor with most investigators as changing the configuration of the finite-elements can alter the results considerably.

Euclidean distance matrix analysis

Euclidean distance matrix analysis (EDMA) was proposed by Lele and Richtsmeier (1991) as an coordinate-free method for analyzing size and shape information captured by landmark coordinates. For each configuration, the procedure requires calculation of all possible interlandmark distances for the landmarks under

consideration. These interlandmark distances are formatted as a distance or form matrix that is used to generate a form difference matrix containing the ratio of corresponding distances from the configurations of interest. These ratios can be ranked and interpreted based on magnitude and anatomical location. This approach has been extended to growth difference matrices for interpreting allometric change (Lele and Richtsmeier 1995).

Pertinent Applications of Geometric Morphometry to Anthropological Research

Early research employing coordinate data by Benfer (1975) and Dickel (1980) derived three-dimensional coordinates from a series of interlandmark distances observed on human crania. Benfer (1975) pioneered the approach of using a triangulation scheme for calculating landmark coordinates with a program known as SKULL. He advocated the application of rotated principal component analysis directly to the coordinates and was able to detect factors that reflected morphological variation. Based on the results obtained from this approach, he noted that the description of asymmetry and simultaneous detection of variation in more than one direction (e.g. breadth and height) was greatly enhanced.

Dickel (1980) employed landmark coordinates as a measure of metric variation in his investigation regarding the congruence of metric and non-metric variables of the human cranium. He employed Benfer's (1975) SKULL program for computing three-dimensional landmarks from a series of interlandmark distances and subjected the coordinates to rotated principal component analysis. Dickel (1980) was also able to identify factors reflecting morphological variation that generally agree with those of

Benfer (1975) and Howells (1973); however, he failed to find satisfactory congruence between distance measures based on metric and non-metric variables.

A particularly interesting application of geometric morphometric methods is Cheverud et al.'s (1992) study of cranial deformation. Finite-element scaling was used to investigate the effects of fronto-occipital cranial modification on the dimensions of the cranial base and face. Three dimensional coordinates were recorded on two series containing both modified and unmodified crania and nine finite elements were defined for the scaling analysis. The results demonstrate that fronto-occipital reshaping of the cranium significantly alters the vault, cranial base and face, but for the two samples used, the modification produced different patterns of morphological change.

O'Higgins and Dryden (1993) looked at sexually dimorphic size and shape differences in the crania of chimpanzee, gorilla and orangutans. They used several different morphometric methods and compared results for points of agreement. Two dimensional configurations are superimposed via an edge-matching method generating Bookstein's shape variables that were subjected to Cartesian transformation grids (thin-plate spline), finite element analysis and biorthogonal grids. All methods demonstrated that the difference between male and female chimpanzees was purely a function of scaling (size differences) whereas significant shape differences between the sexes were evident for gorillas and orangutans. Most of the shape related sexual dimorphism was confined to the facial region with males expressing a relatively greater degree of facial prognathism. The ability to factor out size from the comparison of shape differences permitted the nature of this dimorphism to be recognized.

Lynch et al. (1996) compared various methods for investigating craniofacial variation for humans and chimpanzees. Two dimensional landmarks extracted from lateral radiographs were analyzed via shape coordinates (virtually identical to those of Bookstein 1991), thin-plate spline analysis and relative warp analysis. For humans, Lynch et al. (1996) found little of the size variation present among human populations to be relevant to shape variation. They also noted that some previous research using interlandmark distances to assess relative landmark positions was not necessarily accurate in the presentation of change in landmark location. This is primarily due to the difficulty of interpreting shape change in a region (such as the cranial base) from multiple interlandmark distances. For instance, lengthening of the cranial base can be the result of more anteriorly placed facial landmarks, more posteriorly located landmarks of the cranial base such as basion or differences in both the face and base may exist. Since interlandmark distances do not maintain the geometric relationships of the landmarks relative to one another, an accurate assessment of the nature of shape change can be elusive. However, interpretations of landmark positions relative to all other landmarks based on coordinate data can provide a more accurate picture of the shape change occurring. Additionally the graphic representations of shape variation were found to be quite beneficial for interpretive purposes.

Both Wood and Lynch (1996) and Ahlstrom (1996) investigated sexual dimorphism in size and shape for modern human crania; however, the different approaches produced substantially different results. Wood and Lynch (1996) utilized shape coordinates derived from two dimensional landmark coordinates extracted from

lateral radiographs to compare patterns of dimorphism for Romano-British and African samples. Only the Romano-British sample exhibited significant size related dimorphism, but no shape variation was evident. Conversely, shape variation was present for the African sample primarily related to the amount of prognathism, but no size differences were detected. These results reflect the population specific nature of both size and shape related sexual dimorphism.

Ahlstrom (1996) employed three dimensional coordinates recorded from medieval crania from a cemetery in central Sweden in a thin-plate spline analysis of sexual dimorphism. He found both significant size and shape differences between the sexes. Specifically, Ahlstrom (1996) found that inferior-superior and anterior-posterior directed differences between males and females is most likely related to the mechanical loadings of the muscles of mastication and neck. Females exhibit a relaxation of the occipital region with inion and basion located more posteriorly on females and the temporal region as indicated by the more superiorly positioned bregma and postero-inferiorly oriented stephanion. This study provides illuminating insight into the shape differences between males and females.

A particularly enlightening investigation of the morphological variation present between the crania of Neandertals, archaic *Homo sapiens*, early modern and modern humans is described in Yaroach (1996). Using two dimensional shape coordinates and thin-plate spline analysis, she refutes several accepted interpretations of Neandertal cranial morphology. In particular she determined that no real midfacial prognathism in excess of what is present in early moderns can be observed and that the Neandertal crania

do not exhibit relatively larger orbits as traditionally described. Additionally, this graphical approach to shape variation permitted Yaroeh (1996) to recognize an aspect of Neandertal facial morphology that had not been recognized previously, a twisting of the orbitozygomatic region. Overall Yaroeh (1996) finds that Neandertal crania are not as unique as previously thought. A relative warp plot which displays relative distances among groups or specimens based on the non-affine differences in configurations demonstrates that the Neandertal morphological pattern is more similar to the modern human pattern than the archaics.

Ross et al. (1999) compares morphological patterns associated with crania from American whites and blacks employing three dimensional coordinates and Procrustes analysis. Landmark coordinates were calculated from interlandmark distances based on a triangulation scheme and then subjected to a general Procrustes fitting. Shape differences between the groups were interpreted from visual representations of the Procrustes mean configurations and Euclidean distances were utilized to test the utility of the coordinates for allocating crania to their respective groups. The Euclidean distances worked almost as well as traditional linear measurement based discriminant functions for allocation purposes. More importantly, while many of the differences observed between the groups were not unexpected, variation in the anterior-posterior and inferior-superior position of some landmarks typically associated with breadth measurements was also evident.

Since geometric morphometric methods generally remove absolute size from the data being analyzed, it is a particularly appealing approach for researchers interested in growth and allometry. O'Higgins and Vidarsdottir (1999) compare allometric growth

trajectories for the facial architecture of Aleutian and Alaskan subadult samples utilizing general Procrustes and thin-plate spline analyses. A comparison of adult morphologies demonstrates the presence of significant differences that might be the product of difference in growth and development. However, the growth allometries for the two populations are not significantly different. It appears that differences in adult morphology are primarily due to differences in midfacial prognathism and nasal projection that develop before the first postnatal year and are maintained throughout the growth period.

In summary, geometric morphometry provides methods that permit the efficient analysis of landmark data for the purposes of testing for statistical significance and graphical displays for interpretative purposes. The tools associated with the genre of statistical methods are varied, but strive to accomplish a common goal, quantification of shape variation and change from coordinate data. Application of these methods to questions of anthropological import have been quite successful and have frequently provided unique insights into human biological variability.

CHAPTER 3

ARIKARA CULTURE HISTORY AND BIOLOGICAL VARIABILITY

Archaeological Framework

Archeological evidence indicates that humans occupied the North and Central Plains by at least 12,000 years ago. The culture history of this region is generally divided into five broad periods: Paleo-indian, Archaic, Woodland, Plains Village and Historic (Wedel 1986, Wood 1998, Zimmerman 1985). Differences in technology, subsistence, settlement patterns and to a lesser extent, social attributes, define these periods. While these periods are sequential with the Paleo-indian period representing the earliest manifestation and the Historic period beginning with European contact and continuing to the present, they are no set temporal or spatial parameters for these periods across the Plains. However, smaller subareas may have temporal or spatial defining characteristics associated with a local sequence (Wood 1998).

During the Paleo-indian period, highly mobile bands of hunters and gatherers roamed the Plains following big game herds. The Archaic period is characterized by nomadic foragers with more limited geographic ranges and increased adaptation to local environments as compared to the preceding Paleo-indian cultures. The populations of the Woodland period started to develop horticulture, incorporating corn, beans and squash into their diets, and became less nomadic due to the need to tend crops during the growing season. These cultural changes anticipated the development of the full-scale sedentary villages that marked the Plains Village period.

Four cultural traditions are encompassed within the Plains Village Period. The peoples of the Middle Missouri Tradition lived in large, fortified villages distributed along the Missouri River in North and South Dakota. It is believed that these peoples were Siouan speakers who ultimately culminated in the historic Mandan and Hidatsa (Lehmer 1971). The Central Plains Tradition populations were distributed along the Missouri River in Nebraska as well across more western areas of Nebraska and Kansas. These Caddoan-speaking peoples most likely represent the ancestral populations for the historic Arikara and Pawnee. The populations of the Oneota Tradition were primarily distributed across parts of Iowa, Minnesota and Wisconsin (Key 1983). As such, they are not critical to an understanding of Arikara culture history and will not be discussed further. While the Coalescent Tradition was initially interpreted as a blending of the preceding Central Plains and Middle Missouri Traditions (Lehmer 1971), recent research had demonstrated that the early Coalescent is a direct outgrowth of the Central Plains Tradition (Johnson 1998).

The Coalescent Tradition is divisible into 3 temporal variants: an Initial Variant, an Extended Variant and a Post-contact Variant. As it was initially perceived the Coalescent Tradition had a fourth variant, the Disorganized, that represented the Historic Native American populations from this region prior to the Reservation period (Lehmer 1971). Recent works have revised the treatment of this variant. Blakeslee (1994) considers the Post-contact Variant as the commencement of the Historic Period. Conversely, Johnson (1998) incorporates historic sites such as Leavenworth (39CO9) into the Post-contact Variant without removing the variant from the Coalescent Tradition. For

the purposes of this research, I classify Leavenworth according to Johnson's (1998) most recent archaeological taxonomy.

The Initial Variant dates between AD 1300 and 1600 and appears to be an intrusion of Central Plains Tradition populations into northern Nebraska and southern South Dakota where they built fortified villages along the Missouri River (Blakeslee 1994, Johnson 1998). The populations of the Extended Coalescent (AD 1400/1450-1650 AD) spread northwards along the Missouri River trench most likely pushing the Middle Missouri Tradition peoples ahead of them. During the Extended Coalescent, villages were typically unfortified except in the northernmost aspects of the range in the Grand-Moreau Region where conflict was probably more common with the Middle Missouri Traditions peoples living just to the north in North Dakota (Blakeslee 1994, Johnson 1998). Four phases have been recognized for the Extended Variant: Shannon, Le Compte, La Roche, and Akaska. Most Extended Coalescent sites are attributed to the La Roche phase (Johnson 1998).

The Post-contact Variant is characterized by the appearance of Euro-American trade goods and its inception is dated to 1650 (Lehmer 1971, Johnson 1998). Post-contact villages have been discovered as far north as the confluence of the Knife and Missouri Rivers in North Dakota and continue south into the Central Plains subarea along the Platte and Loup rivers of Nebraska. The occupants of these villages were the protohistoric and historic Mandan, Hidatsa, Arikara, Pawnee, Cheyenne and Ponca (Johnson 1998). Currently nine phases are recognized for the Post-contact Coalescent for

the Middle Missouri Region: Felicia, Talking Crow, Bad River, Le Beau, Knife River, Willows, Minnetaree, Roadmaker and Four Bears (Johnson 1998).

The phases of the Post-contact Coalescent attributed to the protohistoric Arikara are Felicia, Talking Crow, Bad River and Le Beau and warrant further description. Ceramic styles are often the defining characteristics that distinguish between the various phases. The Felicia phase most likely dates at 1650 to 1700 and is immediately followed by the Talking Crow phase dating at 1675-1750 (Johnson 1998). Most of the Felicia and Talking Crow phase sites are located in the Big Bend region of the Missouri with some sites in the Bad-Cheyenne area. The Bad River phase (Hoffman and Brown 1967, Lehmer 1971, Lehmer and Jones 1968) is represented by numerous sites, most of which are located on the west (right) bank of the Missouri River, in the Bad-Cheyenne region and several sites in the Big Bend region. Johnson (1998) proposes a revised temporal span for the phase of 1650-1800. Two temporally sequential subphases are recognized, Bad River 1 and Bad River 2, based on the presence or absence of the artifacts and items indicative of full-scale contact with Euro-American culture. Le Beau phase sites are generally found on the east (left) bank of the Missouri River concentrated in the Grand-Moreau region with a few sites in the Bad-Cheyenne region to the south. Johnson (1998) proposes revised dates of 1650-1785 for the Le Beau phase villages. The historically documented Leavenworth site is also included in the Post-contact Variant of the Coalescent Tradition (Johnson 1998) and represents the last occupation of a village in the Missouri River valley of South Dakota by the Arikara. Table 3.1 outlines the relevant cultural units for interpreting Arikara culture history.

Table 3.1 Cultural units relevant to understanding Arikara culture history.

Paleo-indian Period

Archaic Period

Woodland Period

Plains Village Period

Central Plains Tradition

Middle Missouri Tradition

Oneota Tradition

Coalescent Tradition

Initial Coalescent Variant (1300-1600)

Extended Coalescent Variant (1400/1450-1650)

Shannon Phase

Le Compte Phase

La Roche Phase

Akaska Phase

Post-Contact Coalescent Variant (1650-1862)

Felicia (1675-1700)

Talking Crow (1650-1700)

Bad River (1650-1800)

Le Beau (1650-1785)

Knife River

Willows

Minnetaree

Roadmaker

Four Bears

Historic (Euro-American)

Arikara Culture History

The Arikara of the late prehistoric, protohistoric and historic periods were Caddoan speaking horticulturalists who occupied villages along the banks of the Missouri River in South Dakota. The area along the Missouri River in North and South Dakota is known as the Middle Missouri Region and subareas were occupied by the Arikara, Mandan and Hidatsa tribes during the last few centuries prior to contact with Euro-Americans.

It has long been accepted that the Arikara diverged from the Pawnee in prehistoric times. Striking similarities in oral traditions (Dorsey 1904) and language (Parks 1979a, Tabeau in Abel 1939), as well as the acknowledged association between the two tribes by early Euro-American traders and explorers (Bradbury in Thwaites 1904, Lewis and Clark in Thwaites 1969, Tabeau in Abel 1939) all attest to the veracity of this assumption. Based on linguistic evidence, Parks (1979a) proposes a separation date of 500 BP (approximately AD 1450) for the Arikara-Pawnee split. Subsequently the Arikara moved north into the southern aspects of the Missouri River trench in South Dakota. The earliest sites that potentially represent the prehistoric antecedents of the Arikara are found in the Big Bend region and are attributed to the Initial Coalescent. These villages were heavily fortified and evidence of a brutal massacre at the Crow Creek site (39BF11) (Willey 1990, Willey and Emerson 1993) indicates the presence of pervasive inter-village or inter-tribal conflict. The intrusion of the Initial Coalescent populations into land occupied by Middle Missouri Tradition groups could have sparked such hostilities. Other

possible explanations include clashes among Initial Coalescent villages for access to various resources.

It is believed that the Arikara continued to move north along the Missouri River trench driving the Middle Missouri peoples ahead of them. During the Extended Coalescent the range of prehistoric Arikara villages extended as far north as the Grand River. The earthlodge villages of the La Roche phase sites were generally not fortified, except for the northernmost villages that were probably experiencing conflict with Terminal Middle Missouri Tradition populations to the north.

The introduction of Euro-American items commenced the Post-contact Variant. While direct contact between the Arikara and Euro-American traders and explorers probably did not occur until the mid-18th century, Native American trade routes brought Euro-American goods to the Middle Missouri region much earlier. It appears that the Arikara were middlemen in the fur trade, exchanging furs received from tribes farther to the west for items obtained from eastern tribes who were in direct contact with the Euro-Americans (Holder 1970). During this time, large villages developed along the east (left) bank of the Missouri River, most of which are attributed to the Le Beau phase. The presence of thick midden deposits in conjunction with Euro-American trade goods argues for extended occupations of these post-contact period villages (Johnson 1998). The Bad River phase sites are generally smaller and seem to represent short-term occupations as the villagers probably moved every six or seven years when resources became depleted (Hoffman and Brown 1967).

Due to their location high on the Missouri River, the Arikara were one of the last tribes to come into direct contact with the Euro-American traders and explorers. As the fur traders and explorers ventured further along the Missouri River, in both northerly and southerly directions, interactions with Arikara villages increased. One of the earliest Europeans reports of the Arikara comes from Bourgmont in 1717 who describes the “Arikara and Caricara villages, six hundred leagues up the river” (Nasatir 1952:13). As early as 1734, Governor Bienville of Louisiana writes of a Frenchman who had resided for many years with the Pani-mahas (Pawnees) and had accompanied them up river to visit the ‘Ricaras’ who had yet to see any Frenchmen (Nasatir 1952:25). Louis and Francois La Verendrye descended the Missouri River from Canada and traveled west in search of Indians with which to trade for horses. They eventually turned back and ended up spending several months with the Arikara before leaving in April 1743 to return to Montreal (Nasatir 1952). Trudeau visited the Arikara in 1795 at two villages on the west bank of the Missouri River approximately three miles below the mouth of the Cheyenne River (Trudeau 1914). Already the traditional societal structure was beginning to breakdown as dissension among four chiefs resulted in two bands seceding, one traveling south to live with the Pawnee and one moving north to reside with the Mandan. After apparently moving upstream and living in North Dakota for a period of time, the Arikara were again living in South Dakota when they were visited by Tabeau and Lewis and Clark in 1804. During this time they were residing in three villages, one on present day Ashley Island and the other two villages were separated by a small creek on the right bank of the Missouri near the mouth of the Grand River (Lewis and Clark in Thwaites 1969).

These villages were later attacked by Colonel Leavenworth in retaliation for Arikara aggression towards General Ashley's trading party and are now known as the Leavenworth site. The island village was abandoned some time prior to 1811 when the Arikara were visited by Brackenridge and Bradbury at Leavenworth (Thwaites 1904). During their occupation of the Leavenworth villages the Arikara were alternately allied or in conflict with their Mandan neighbors to the north as well as being constantly harried by the Sioux to the west. After a temporary absence from the Leavenworth villages following the shelling by Colonel Leavenworth in 1823, the Arikara resided in the villages until their removal in 1832 when they were forced to live along the Platte River (Ewers 1961). They returned to the Missouri River in 1836 and moved into Ft. Clark in 1837 where they resided with the Mandan and Hidatsas (Chardon in Abel 1932).

Depopulation due to disease, internal dissension and pressure from Plains nomadic groups such as the Sioux were primary factors in structuring population movement during the period described ethnographically. In 1795, Trudeau (1914) claims that the Arikara had occupied 32 villages prior to three small pox epidemics that had reduced population numbers such that only three villages remained. Tabeau (in Abel 1939) records the original village number as 18 during his stay in 1804 and noted that the three current villages were composed of ten different tribes with as many chiefs. He also recognized dialect differences among the groups of Arikara residing these villages. The conflict between the Arikara and the Mandan and Hidatsa to the north and the Sioux from the west was also documented by Tabeau (in Abel 1939). In 1807, during a voyage up the Missouri to return a Mandan chief to his village, Manuel Lisa and Hiram Chittenden's

boat was fired upon by the Arikaras as it approached the lower village at Leavenworth. The Arikara were currently at war with the Mandan at the time and did not care to let a Mandan chief aboard on the boats in the party to pass their village. Negotiations were attempted, but the boats had to return to St. Louis without venturing beyond the Arikara village. According to Chittenden (1935) thus began a 20 year period of conflict between the Arikara and white traders that led to the attack by Colonel Leavenworth in 1823 and eventual removal from the Missouri River valley in 1832.

Variation in Cranial Morphology among the Arikara

While archaeological research has a long history in the Middle Missouri Region of the Northern Plains, studies into the biological nature of the prehistoric and historic populations lagged far behind (Bass 1981). Early studies such as Morton's 1839 *Crania Americana* and Boas' 1895 paper on Native American biological variability used individual crania or very small samples from Plains tribes including those from the Middle Missouri Region. In particular, Morton (1839:258) included cranial measurements from one Pawnee cranium, one Mandan cranium and one "Ricara" cranium and Boas (1895:396) lists cranial indices for four Arikara, ten Pawnee and nine Mandan specimens. Until Bass' (1964) study of the relationship between crania from several known and putative Arikara sites, a Pawnee sample and a Central Plains Tradition sample, little had been done with the skeletal material beyond listings in appendices attached to archaeological reports.

Understanding that the analysis of human skeletal material provides one of the most insightful avenues for learning about the lives and deaths of past populations, Bass and others pressed their archaeological colleagues to retain skeletal material from their excavations. Archaeologists began responding to these requests and Bass himself directed field projects from the late 1950s and into the 1960s designed to collect large series of skeletal samples from the Middle Missouri Region (Bass 1981). The inundation of reservoirs along the Missouri River trench in South Dakota in the 1960s intensified archaeological investigations in the Middle Missouri region producing ever larger skeletal samples, many of which are attributed to the Arikara and their antecedents. With these extensive series at their disposal, researchers have used cranial morphology to investigate the patterns of biological variation present among and within the sites attributed to the Arikara including: temporally patterned microevolutionary change, the origins of the Arikara, their relationships with other tribes from the Middle Missouri Region such as the Mandan and the Pawnee as well as the presence and meaning of intrasite variation.

The first of these studies sought to establish the affinity of probable Arikara sites with known Arikara sites and investigate the prehistoric origins of the tribe. Employing a series of 11 cranial measurements observed on adult males from six known and “putative” Arikara sites (Cheyenne River [39ST1], Leavenworth [39CO9], Mobridge [39WW1], Nordvold [39CO31, 32-33], Sully [39SL4], and 39ST216), a Pawnee sample and a Central Plains sample, Bass (1964) investigated the biological relationships among the groups and the morphological patterns that exemplified each group. In particular, Bass (1964) was interested in establishing the relationships between the earlier, southern

sites thought to be associated with the protohistoric Arikara (Cheyenne River, Sully and 39ST216) and the later, northern sites that were attributed to the Arikara (Leavenworth, Mobridge and the Nordvolds) as well as showing relationships between the Arikara, the Pawnee and the preceding Central Plains Tradition populations. The affinity among individuals from the southern sites was interpreted as evidence for membership in the same protohistoric population. The samples from the northern Arikara sites were found to be relatively heterogenous but appeared to be related to the protohistoric sites.

Comparison of the Arikara sites and the Pawnee sample demonstrated that the northern and southern Arikara sites are more similar to one another than they are to the Pawnee sample supporting the hypothesized relationship between the sites attributed to the Arikara. While the Arikara and Pawnee samples exhibit significant differences, the variation was not considered great enough to preclude a common ancestry for the two groups. The Central Plains Tradition sample was found to be significantly different from both the Arikara and Pawnee samples which did not support an origin for both of the later populations from Central Plains Tradition populations. Bass (1964) did recognize a temporal trend involving a decrease in average basion-bregma height through time for the sample indicating that low cranial vaults among historic Plains populations is a recent occurrence.

More comprehensive studies of variability among Middle Missouri Region sites attributed to the Arikara soon followed including Jantz (1970, 1972, 1973), Lyon (1970), Lin (1973), and Key and Jantz (1981). Jantz's early research (1970, 1972) focused on variation among six sites (Rygh [39CA4], Mobridge [39WW1], Sully [39SL4], Larson

[39WW2], Cheyenne River [39ST1] and Leavenworth [39CO9]) to assess the inter-site relationships. Jantz (1970) employed both metric and non-metric variables observed on crania from available series and found that the craniometric evidence supports a temporal dichotomy that reflects increasing heterogeneity through time. However, this dichotomy was not as clearly indicated by the non-metric data which seemed to reflect a geographically defined cluster in the Mobridge area including the sites of Rygh, Mobridge and Larson. Jantz (1970, 1972) proposed that the increasing heterogeneity through time indicated by the craniometric data could be a result of depopulation, disease selection and gene flow from outside populations including European traders and explorers. These hypotheses are supported by European trader and explorer accounts (Tabeau in Abel 1939, Trudeau 1914) which describe the Arikara encountered at Leavenworth as being the remnants of just a few Arikara families who survived small pox epidemics. Additionally, ethnographic accounts (Brackenridge in Thwaites 1904, Bradbury 1904, Tabeau in Abel 1939, Trudeau 1914) provide evidence for admixture with both Europeans and other Native American groups in the area. Both of these factors, either independently or in concert, could contribute to increased heterogeneity among the later samples.

Jantz (1973) expanded on his previous research by including British white and Mandan comparative samples to test the gene flow hypothesis. Canonical discriminant analysis employed 15 cranial measurements from five Arikara samples (Rygh [39CA4], Mobridge [39WW1], Sully [39SL4], Larson [39WW2] and Leavenworth [39CO9]) derived three canonical variates that effectively discriminate between the groups for both

the males and females. A temporal canonical axis is present for each sex indicating the relative temporal ordering of the sites. For the females, Sully is separated from the other four sites along another canonical variate most likely reflecting its geographically distinct location. Morphological changes identified along these temporal axes include an increase in nasal breadth and decreases in orbit width, basion-nasion length and cranial vault height. Overall, the measurements of facial dimensions show greater variability than the vault measurements which is reflected in the variable loadings on the canonical variates. Jantz (1973) attributed this temporal change in morphology to gene flow from nearby Native American groups such as the Mandan and from white traders and explorers. To test this hypothesis, the Leavenworth, Sully and Larson samples were classified using discriminant functions generated based on an Arikara sample consisting of a pooled Rygh-Mobridge data set and data sets from the two comparative samples, British Whites and Mandan. While the mean for both sexes was slightly displaced towards the white mean among the later sites, it appears that the effect of such interbreeding was minimal. On the other hand, the Arikara-Mandan comparison portrays a shift in the Arikara mean towards the Mandan mean for both sexes from the later sites. The mean for the Leavenworth site is almost intermediate between the Mandan and Arikara mean with 35% of the males and 33% of the females being misclassified as Mandan. This suggests that much of the morphological change through time is related to increasing levels of gene flow from the Mandan, which is particularly evident among the sample from the historic Leavenworth site.

Temporal trends for Arikara cranial morphology were also recognized by Lyon (1970) and Lin (1973). Lyon (1970) demonstrated significant variation among three Arikara sites (Sully [39SL4], Larson [39WW2] and Leavenworth [39CO9]) partly defined by a temporal trend in auricular height (distance from porion to apex), a measure of head height. In particular, a sharp increase in this measurement was evident between Sully and Larson for both males and females which was interpreted as indicating an increase in head height through time. Lin (1973) was primarily interested in establishing the affinity of individuals from the Rygh site (39CA4). A discriminant analysis employing individuals from Rygh, Mobridge (39WW1), Sully (39SL4), Larson (39WW2), Leavenworth (39CO9) and a Mandan sample clearly demonstrated that Rygh is most similar to the Arikara samples and should not be attributed to the Mandan. Lin (1973) also noticed an apparent temporal trend in cranial length for the Arikara samples. He contends that an increase in glabella-occipital length through time triggers corresponding changes in cranial morphology including an increase in the length of the anterior half of the cranium as well as a lengthening of the occipital.

Later research uses greater sample sizes and includes more cranial measurements in an effort to better understand the temporal trend demonstrated in Jantz's (1970, 1972, 1973), Lyon's (1970) and Lin's (1973) early works. Key and Jantz (1981) utilized principal component analysis and multiple regression with time as the independent variable to identify temporal trends in cranial morphology among Arikara samples. Variation in several dimensions were significantly associated with time and it was noted that a substantial proportion of the inter-site variation is due to the temporal trend.

Specifically, through time facial height increases as does arching of the frontal bone while basion-bregma height remains constant or slightly decreases. Significant variation in lower facial prognathism, anterior vault height and foramen magnum size was present but was not temporally patterned.

An overarching analysis of populations from the entire Plains region is detailed by Key (1983) and employed samples from the Paleo-indian through Historic periods. Utilizing 80 cranial measurements and indices, Key (1983) investigated variation in cranial morphology across time and space. Pertinent to the present study are Key's (1983) findings regarding the Coalescent Tradition and Historic period Arikara. A canonical correlation analysis utilizing principal component scores indicated that variation is significantly related to time and geography. Specifically, greater angulation of the occipital, a decrease in vault height and increase in face height are associated with the passage of time and movement northward along the Missouri River trench. It appears that this trend begins in the ancestral Central Plains Tradition populations and continues through to the Historic manifestation of the Arikara culture. Key noted that the morphological pattern exhibited by crania from the later Arikara samples begins to look more Mandan-like most likely due to increasing levels of gene flow between the two groups.

Further evidence for gene flow from the Mandan, particularly during the historic period is provided by analysis of the burials from the Leavenworth (39CO9) site (Bass et al. 1971) and by a comparison of Leavenworth and Mandan crania (Owsley and Symes 1981). Bass et al. (1971) evaluated craniometric data from the Leavenworth sample with

respect to other Arikara sites as well as samples from Central Plains Tradition, Pawnee, Mandan, Austrians and Norse populations. Based on the generalized distance values, the Leavenworth males are most similar to the males from the other Arikara sites, Sully (39SL4) and 39ST215/216 while the Leavenworth females are closest to the females from Sully and the Mandan sample followed by 39ST215/216. The similarity among Sully, 39ST215/216 and Leavenworth indicates that the first two protohistoric sites are ancestral to the historic Leavenworth. The similarity between Leavenworth females and the Mandan females was interpreted as evidence for possible gene flow between the historic Arikara and Mandan.

The morphological differences that separate crania from Leavenworth (39CO9) and a historic Mandan sample were investigated by Owsley and Symes (1981). The two samples are significantly different and can be distinguished based on variation in face and vault dimensions. Specifically, the Mandan crania are narrower with lower auricular and nasal heights than the Leavenworth crania. This pattern of morphological differences lends further support to the hypothesis that the changes in Arikara crania occurring through time can be attributed to gene flow with their Mandan neighbors.

Evidence from cranial morphology has been used to support a shared ancestry with the Pawnee and an evolutionary history that stretches back into the Central Plains Tradition populations. One of the earliest attempts to establish the ancestry of the protohistoric and historic manifestation of the Arikara was Alexander's (1971) study comparing samples from various Arikara sites with Woodland, prehistoric and historic Pawnee, Ponca-Omaha and Mandan samples. The Arikara sample was most similar to

the Pawnee samples followed by the Mandan sample which Alexander (1971) interpreted as supporting a hybrid origin for the Arikara populations of the Middle Missouri Region. Such a hybridization would involve gene flow from both the ancestral Pawnee and the Mandan populations and would account for the similarities among the Arikara and these two samples.

The relationships among Plains populations are examined from an evolutionary and historical perspective by Jantz (1977) providing evidence for tribal origins as well as evaluating the position of the Arikara relative to other Middle Missouri Region populations. Based on craniometric data from Arikara, Pawnee, Mandan, and Central Plains Tradition samples, Jantz (1977) demonstrated the similarity between early Arikara samples and the preceding Central Plains Tradition samples from northern Nebraska indicating that the Coalescent Tradition Arikara are descendent from the Central Plains Tradition groups to the south. An analysis employing only auricular-mean height index incorporated an expanded test sample including crania from the Archaic and Woodland periods, Central Plains, Middle Missouri and Coalescent Traditions and Historic period Arikara, Pawnee, Omaha and Mandan. While a continuous decrease in auricular-mean height index is evident for the Central Plains Archaic through the South Dakota Coalescent, the Northern Plains groups exhibit fairly low values for the index throughout the time period. However, the historic samples are remarkably similar considering their varied evolutionary and cultural histories indicating that substantial gene flow had occurred among the groups as they approached the historic period. Archaeological and ethnographic evidence also suggests increasing interaction among these groups due to

trade networks and the social breakdown that accompanied exposure to European traders and the disease epidemics that soon followed. Studies by Jantz et al. (1978), Ubelaker and Jantz (1979) and Jantz et al. (1981) also demonstrate the similarity between St. Helena phase sites of the Central Plains Tradition with later Arikara populations of the Coalescent Tradition further supporting biological continuity between the two groups.

The origins of the Arikara tribe have been assessed from the perspective of the Crow Creek site (39BF11) by Willey (1990). The Crow Creek site located along the southern aspect of the Missouri River in South Dakota provides evidence for an Initial Coalescent occupation of a fortified village during the mid-1300s. Recovered skeletal material associated with this component are massacre victims (Willey 1990, Willey and Emerson 1993). Craniometric analyses reported in both Willey (1990) and Willey and Emerson (1993) indicate that the Crow Creek sample is most similar to a contemporaneous St. Helena sample and early Arikara samples (Rygh [39CA4], Mobridge [39WW1] and Sully[39SL4]). The contemporaneity of the St. Helena and Crow Creek samples would suggest that gene flow is responsible for the similarity between the two samples. The similarity between the Crow Creek and early Arikara sites is interpreted as evidence that the Crow Creek residents were members of the population that gave rise to the later Arikara sites.

Several studies consider the relationship of the Arikara to other sites from the Central and Northern Plains seeking to understand the morphological variation present among the Coalescent Tradition populations. Jantz et al. (1981) examined the intergroup relationships of the Central Plains and Coalescent Tradition sites with historic Pawnee,

Arikara and Siouan speaking Mandan, Omaha and Ponca. The homogeneity of the Coalescent Tradition sites attributed to the Arikara is supported by a tendency for individuals from these sites to misclassify into each other except for Sully, which has individuals misclassifying as Mandan, Pawnee and St. Helena. A distinct division among the Caddoan and Siouan speaking groups is evident, primarily reflecting differences in cranial vault height. Earlier sites associated with the Caddoan speakers exhibit higher cranial vault heights with the Omaha and Ponca samples possessing the lowest heights. The temporally intermediate Arikara sites fall towards the early Caddoan end of the continuum, the Pawnee are closer to the Omaha/Ponca end and the Mandan are in between. These results suggest probable gene flow between the Arikara and Mandan especially towards the Historic period and between the Pawnee and Omaha/Ponca tribes.

Jantz and Willey's (1983) study of relative head height expanded the geographic, temporal and cultural parameters for investigating temporal trends in craniometrics for samples from the Northern Plains. Employing samples from the Woodland period, Central Plains Tradition, Middle Missouri Tradition, Arikara, Pawnee and Mandan, temporal change in cranial vault height from the Woodland through the Historic period was identified. Utilizing auricular height (distance from porion to apex) as a measure of head height and the auricular mean height index ($AMHI = (\text{auricular height} / (\text{cranial length} + \text{cranial breadth}) \times 0.5) \times 100$), Jantz and Willey (1983) demonstrate that AMHI decreases through time and increases with more northern latitudes. However, they note that the geographic trend is weaker than the temporal trend. It was also observed that the Central Plains Tradition/Arikara/Pawnee samples always exhibit greater head height than

the Middle Missouri Tradition/Mandan samples regardless of temporal period or geography.

During an assessment of three Le Beau phase sites (Four Bear [39DW2], Oahe Village [39HU2], Swan Creek [39WW7]) and one Bad River phase site (Stony Point [39ST235]) from the Middle Missouri Region, Owsley et al. (1981) detected significant differences between the Arikara and Mandan calibration samples. The first canonical variate for the calibration samples separates the early Arikara and Mandan based on cranial vault height and length. The Mandan sample exhibited longer and narrower crania when compared to the early Arikara sample. The samples from the sites in question were most similar to the Arikara; however, a few individuals do classify as Mandan which may indicate the inclusion of Mandan burials at these sites. Swan Creek appears particularly heterogeneous with most of the sample affiliating with various Arikara sites and 22% of the sample classifying as Mandan.

The nature of intrasite variation was also investigated at a number of sites attributed to the Arikara and many of the samples were found to represent temporally or culturally differentiated components. Specifically, temporal differences among the components or features from Sully (39SL4) (Owsley and Jantz 1978) and Mobridge (39WW1) (Owsley et al. 1982) were demonstrated to exist allowing sequencing of the features. For Mobridge, Owsley and coworkers (1982) found that craniometric evidence supported the later temporal position of Feature 2 relative to Features 1 and 3 which had been derived based on the presence or absence of Euro-American trade items. That the variation between burial areas (A, B, D and E) at Sully is also attributable to temporal

differences is demonstrated by Owsley and Jantz (1978). In the temporal sequence constructed for the males, area D is the earliest, followed by areas E and A with area B being the most recent component. However, in the female sequence areas D and E are reversed. Since the male sequence agreed with the archaeological interpretation of the features, it was considered the most appropriate.

Additionally, significant heterogeneity at Leavenworth (39CO9) was indicated by Key and Jantz (1990) suggesting that the excessive variation may be related to differences among the burial areas at the site. A more in-depth analysis by Byrd and Jantz (1994) shows that the heterogenous nature of the Leavenworth sample is due to the composition of the population that occupied the site. As noted by European traders and explorers, the two villages at Leavenworth were inhabited by remnants of a much larger population consisting of numerous villages that were decimated by small pox (Tabeau in Abel 1939, Trudeau 1914, Lewis and Clark in Thwaites 1969). Linguistic differences and the presence of several chiefs from leading families suggests that this population represented the survivors from previously autonomous villages. Comparison of crania from the burial areas at Leavenworth with samples representing the two archaeologically recognized cultural variants of the Arikara, indicates that descendants of both cultural groups were present at Leavenworth and were using separate burial areas, perhaps as a way to maintain cultural identity.

These studies repeatedly demonstrate the similarity between the Coalescent Tradition Arikara and the preceding Central Plains Tradition supporting biological continuity between the two culturally and temporally defined periods. A high degree of

similarity was evident among the sites attributed to the Arikara; however significant differences between sites were also recognized and exploited to investigate the patterns of morphological variation that are present. These studies establish geographical and temporally patterned variation in cranial morphology during the last 200 years of Arikara occupation of the banks of the Missouri River in South Dakota. In particular, temporal trends in the form of increasing vault length and decreasing vault and face height through time are particularly evident in this research. Since 200 years seems an exceedingly short time for natural selection to produce such marked changes in cranial morphology, other causal factors were considered. A particularly appealing explanation involves gene flow from other Native American groups, particularly the Siouan speaking Mandan who occupied the upper reaches of the Missouri River in North Dakota. Evidence from the pattern of morphological change indicates that this hypothesis is highly probable as the Arikara cranium becomes more similar to the Mandan cranium through time. The earliest Arikara samples are characterized as exhibiting taller and shorter cranial vaults with shorter faces. Through time, the cranial vault begins to lengthen and decrease in height while the face increases in height. This pattern of morphological change is most evident among the sample from Leavenworth. It is therefore proposed that the Arikara population which occupied Leavenworth not only represented the amalgamated remains of the Le Beau and Bad River cultures, but also appears to have been receiving considerable gene flow from their Mandan neighbors to the north. It is important to note that these studies indicate that not only was there a decrease in overall vault height for Arikara crania through time, but all Native American groups in this area appear to be

experiencing a concomitant decrease in vault height suggesting that gene flow from outside the region might be influencing overall patterns of cranial morphology.

CHAPTER 4

MATERIALS

Sample

To investigate the change in cranial morphology among samples from cemeteries attributed to the Arikara of the Coalescent Tradition 18 components from variants of the Coalescent Tradition were selected for this study. These components represent approximately 250 years of Arikara history. Table 4.1 provides a summary of site name and number, period, affiliation and approximate dates for each of these sites. The skeletal material from these sites is currently maintained at the Smithsonian Institution, National Museum of Natural History and the Department of Anthropology, University of Tennessee, Knoxville.

These sites from the Middle Missouri region of South Dakota are attributed to the Plains Village 2 (Extended variant), Protohistoric (Post-contact variant) and Historic (Historic Arikara) Periods of the Central Plains-Coalescent Tradition (Blakeslee 1994). The La Roche phase of the Extended Coalescent is represented by Rygh (39CA4), Nordvold 2&3 (39CO32-3), Features 1 and 3 from the Mobridge site (39WW1) and components of the Sully site (39SL4). The Le Beau phase of the Postcontact Coalescent is represented by Nordvold 1 (39CO31), Larson (39WW2), Swan Creek (39WW7), Feature 2 and the Stirling material from the Mobridge site (39WW1) and components of the Sully site (39SL4). The Felicia phase of the Post-contact Coalescent Tradition is

Table 4.1. Coalescent Tradition sites associated with the Arikara used in this study. EC denotes Extended Coalescent and PCC denotes Post-contact Coalescent.

Site Name/ Component	Site Number	Period	Affiliation	Dates
Nordvold 2 & 3	39CO32-3	Plains Village 2	EC, La Roche	1550-1675
Anton Rygh	39CA4	Plains Village 2	EC, La Roche	1600-1650
Mobridge F1	39WW1	Plains Village 2	EC, La Roche	1600-1650
Mobridge F3	39WW1	Plains Village 2	EC, La Roche	1600-1650
Sully A	39SL4A	Protohistoric	EC, La Roche	1650-1675
Sully D	39SL4D	Protohistoric	EC, La Roche	1650-1675
Breeden B	39ST16B	Protohistoric	PCC, Felicia	1675-1700
Mobridge F2 (including Stirling's Cemetery 1)	39WW1	Protohistoric	PCC, Le Beau	1675-1700
Sully E	39SL4E	Protohistoric	PCC, Le Beau	1675-1700
Sully B	39SL4B	Protohistoric	PCC, Le Beau	1679-1733
Swan Creek	39WW7	Protohistoric	PCC, Le Beau	1675-1725
Larson	39WW2	Protohistoric	PCC, Le Beau	1679-1733
Nordvold 1	39CO31	Protohistoric	PCC, Le Beau	1675-1780
Black Widow Ridge	39ST203	Protohistoric	PCC, Bad River 1	1675-1740
Indian Creek	39ST15	Protohistoric	PCC, Bad River 1	1675-1740
Leavitt	39ST215	Protohistoric	PCC, Bad River 2	1740-1792
Cheyenne River	39ST1	Protohistoric	PCC, Bad River 2	1740-1795
Leavenworth	39CO9	Historic	Arikara	1802-1832

(Sources: Billeck 2000 personal communication, Blakeslee 1994, Jantz 1997, Key 1983)

represented by a component of the Breeden site (39ST16). The Bad River 1 and 2 phases of the Post-contact Coalescent tradition are represented by Black Widow Ridge(39ST203), Indian Creek (39ST15), Leavitt (39ST215), and Cheyenne River (39ST1). The Historic Arikara are represented by the Leavenworth site (39CO9).

These sites are distributed along the banks of the Missouri River in South Dakota reflecting the movement of the populations northward along the river valley during this time period. Figure 4.1 depicts the geographic distribution of these sites. There are two major geographic distinctions for these sites. All of the Bad River phase sites, the Nordvold sites and the Leavenworth site are located on the left bank of the Missouri River while all other sites are located on the right bank of the river. While there is temporal overlap between some Bad River and Le Beau phase sites, variation in ceramic styles indicates that the Missouri River served as a barrier to interaction between the populations that inhabited these sites (Lehmer 1971, Lehmer and Jones 1968). Previous studies have also demonstrated that this variation extends to biology as significant differences in cranial morphology also exist between Bad River and Le Beau phase populations (Byrd and Jantz 1994; McKeown and Konigsberg 2000). A second geographic aspect of the site distribution is the North-South orientation of the sites along the Missouri river valley.

Sample sizes vary from site to site based on population size, differential preservation and recovery techniques. Table 4.2 summarizes the number of crania broken down by sex included in this study from each site or site component.

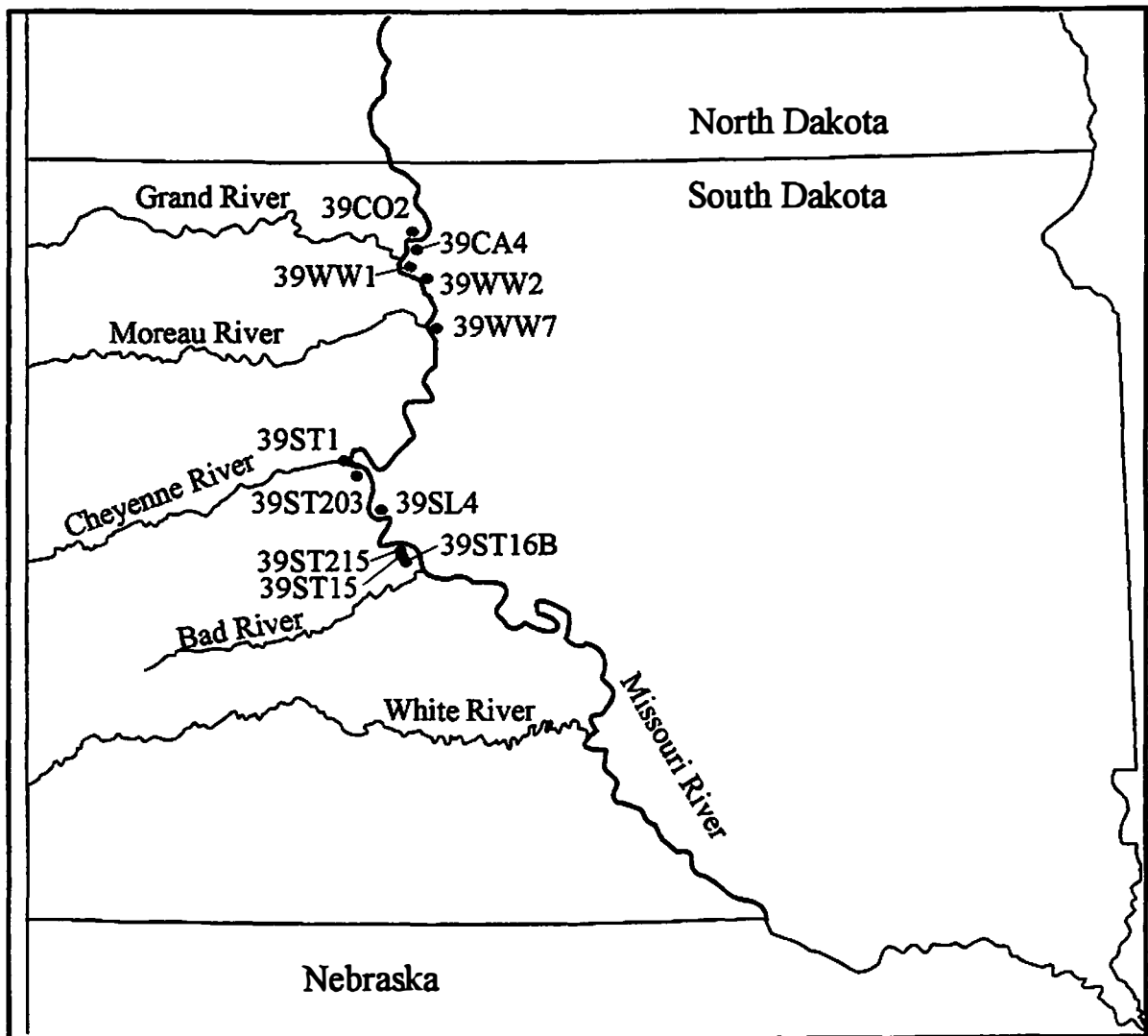


Figure 4.1. Map depicting sites included in this study.

Table 4.2. Sample sizes and abbreviation for each site included in the study.

Site Name/Component	Site Number	Abbrev.	Sample size		
			Males	Females	Total
Nordvold 2 and 3	39CO32-3	ND2&3	19	10	29
Anton Rygh	39CA4	RY	14	12	26
Mobridge F1	39WW1	MBF1	16	19	35
Mobridge F3	39WW1	MBF3	4	4	8
Sully A	39SL4A	SLA	15	7	22
Sully D	39SL4D	SLD	12	13	25
Breeden B	39ST16B	BR	1	1	2
Mobridge F2 (including Stirling's Cemetery 1)	39WW1	MBF2	55	36	91
Sully E	39SL4E	SLE	22	9	31
Sully B	39SL4B	SLB	0	2	2
Swan Creek	39WW7	SC	6	6	12
Larson	39WW2	LA	72	81	153
Nordvold 1	39CO31	ND1	2	1	3
Black Widow Ridge	39ST203	BWR	4	4	8
Indian Creek	39ST15	IC	1	1	2
Leavitt	39ST215	LT	5	1	6
Cheyenne River	39ST1	CR	9	9	18
Leavenworth	39CO	LW	23	26	49

Site Descriptions

Anton Rygh (39CA4)

Located on the left bank of the Missouri River in the Grand-Moreau region, the Rygh site is situated across the river from the Leavenworth site (39CO9) and consists of a village with a cemetery to the west. Exploratory excavations were undertaken in the village area by W.D. Strong in 1932 (Strong 1940) and A.W. Bowers who conducted more extensive excavations between 1959 and 1963 (Bowers n.d. cited in Jantz 1970) during which time several burials were excavated. In 1965 a field crew from the University of Kansas recovered several interments from the cemetery. Additional crania were recovered by amateur collectors or were salvaged as they eroded out of the banks of the Oahe Reservoir (Jantz 1970).

Based on archaeological evidence from the village area, Strong (1940) considered the site to be culturally affiliated with the Mandan. However, the burials were primary interments covered with wood similar to many known Arikara sites (Bass et al. 1971, Wedel 1955). Bowers (n.d. cited in Jantz 1970) identified four occupations (Rygh I, II, III, IV) with only the Rygh IV component producing any European trade goods. The burials excavated by Bowers are attributed to Rygh III (Bowers n.d. cited in Jantz 1970) and the burials recovered by the University of Kansas field party also lacked any European trade goods (Jantz 1970). The other crania are of uncertain provenience due to the nature of their recovery (salvage and amateur collectors). Based on the lack of trade goods associated with the burials of known provenience, the burials from this site are attributed to the La Roche phase of the Extended Coalescent (Jantz 1970). Craniometric

studies (Jantz 1970, Lin 1973, Owsley, et al.1981) have demonstrated a strong affiliation between Rygh and other accepted Arikara sites.

Nordvold 1 (39CO31)

Based on M.W. Stirling's field notes from excavations conducted during June 1923, Wedel (1955) describes Nordvold 1 as a village marked by earthlodge pits and a cemetery north of the village area on the right bank of the Missouri River. The village area is located a few hundred yards northeast of Nordvold 2 and 3 (39CO32-3) in the Grand-Moreau region and encompasses about 2,000 square feet surrounded by a defensive ditch. Stirling excavated six burials in the Nordvold 1 cemetery of which three graves contained glass beads. Due to the presence of European trade goods associated with burials and artifacts collected from the village area by Strong (letter mentioned in Wedel 1955), Nordvold 1 represents a later occupation than Nordvold 2 and 3 and is attributed to the Le Beau phase of the Post-contact Coalescent.

Nordvold 2 and 3 (39CO32-3)

Using M.W. Stirling's field notes, Wedel (1955) describes Nordvold 2 and 3 as two villages with a cemetery located east of the larger village (Nordvold 2). The site is located approximately 3 miles NNE of the Mobridge site on the right bank of the Missouri River in South Dakota. The occupational area is represented by two villages with the larger and potentially older of the two being designated Nordvold 2. Both the southern and northern perimeters of the village areas are marked by defensive ditches. Thirty-nine burials were excavated by Stirling in 1923, most of which were single interments, with at least four more graves excavated by W.D. Strong in 1932. While it

was suspected that the villages were occupied during different temporal periods, it was impossible to ascertain which burials should be ascribed to which village. Since the Nordvold 2 village is the larger of the two occupation areas, the burials from Nordvold 2 & 3 cemetery have traditionally been associated primarily with the earlier Nordvold 2 village attributed to the La Roche phase of the Extended Coalescent.

Leavenworth (39CO9)

The historically occupied villages known now as Leavenworth are separated by about 150 yards and a small creek on the right bank of the Missouri River with a cemetery area about 300 yards northeast of the villages in the bluffs above the river terrace (Bass et al. 1971, Krause 1972, Wedel 1955). The site is located above the Missouri's confluence with the Grand River about six miles upriver from the Nordvold sites (39CO31, 32, 33) and across the river from the Rygh site (39CA4). Each village area contained the impressions for 60 to 80 earthlodges. The upper village was surrounded by a palisade and partial ditch while the only fortification archaeologically recognizable for the lower village is a partial ditch (Krause 1972).

Major excavations were undertaken in the cemetery area by W.H. Over in 1915 and 1917, M.W. Stirling in 1923 (Wedel 1955) and University of Kansas field parties under the direction of W.M. Bass in 1965 and 1966 (Bass et al. 1971). Stirling recovered human skeletal remains from 22 graves, many of which contained European trade goods (Wedel 1955). When exploration of the cemetery area began under the direction of W.M. Bass, it was recognized that the cemetery contained five spatially distinct burial areas which were designated A, B, C, D and E. The University of Kansas field parties

excavated a total of 285 burials with each burial area being represented in the total collection (Bass et al. 1971). However, most of the burials were located in Areas A, B and C and the individuals included in this study from Stirling's excavations are incorporated into Area C. Figure 4.2 is a map of the Leavenworth site including the villages and the separate burial areas in the cemetery.

The occupation dates for Leavenworth are based on historical documentation by American and European explorers and fur traders. In October of 1804 the villages at Leavenworth and a third village on Ashley Island, which is slightly downriver from Leavenworth, were visited by Lewis and Clark as they traveled up the Missouri River searching for a passage to the Northwest (Lewis and Clark in Thwaites 1969). The village on Ashley Island had been abandoned by 1811 when Brackenridge visited the Leavenworth villages (Thwaites 1904). In August of 1823 Colonel Leavenworth shelled the villages in retaliation for a prior attack on fur traders under the command of General Ashley and the Arikara abandoned the village under the cover of night (Chittenden 1935). Maximilian reports that after fleeing Col. Leavenworth's attack, the Arikara moved upriver to settle just south of Ft. Clark near their intermittent allies, the Mandan. Maximilian noted that by the spring of 1824, the Leavenworth villages were once again occupied by the Arikara. Passing by the Leavenworth villages again in June of 1833, Maximilian observed that the villages were abandoned and in a state of disrepair (Maximilian in Thwaites 1904).

Based on the site location and ceramic assemblage recovered from Leavenworth, early assessments generally considered the site to be a historic manifestation of the Bad

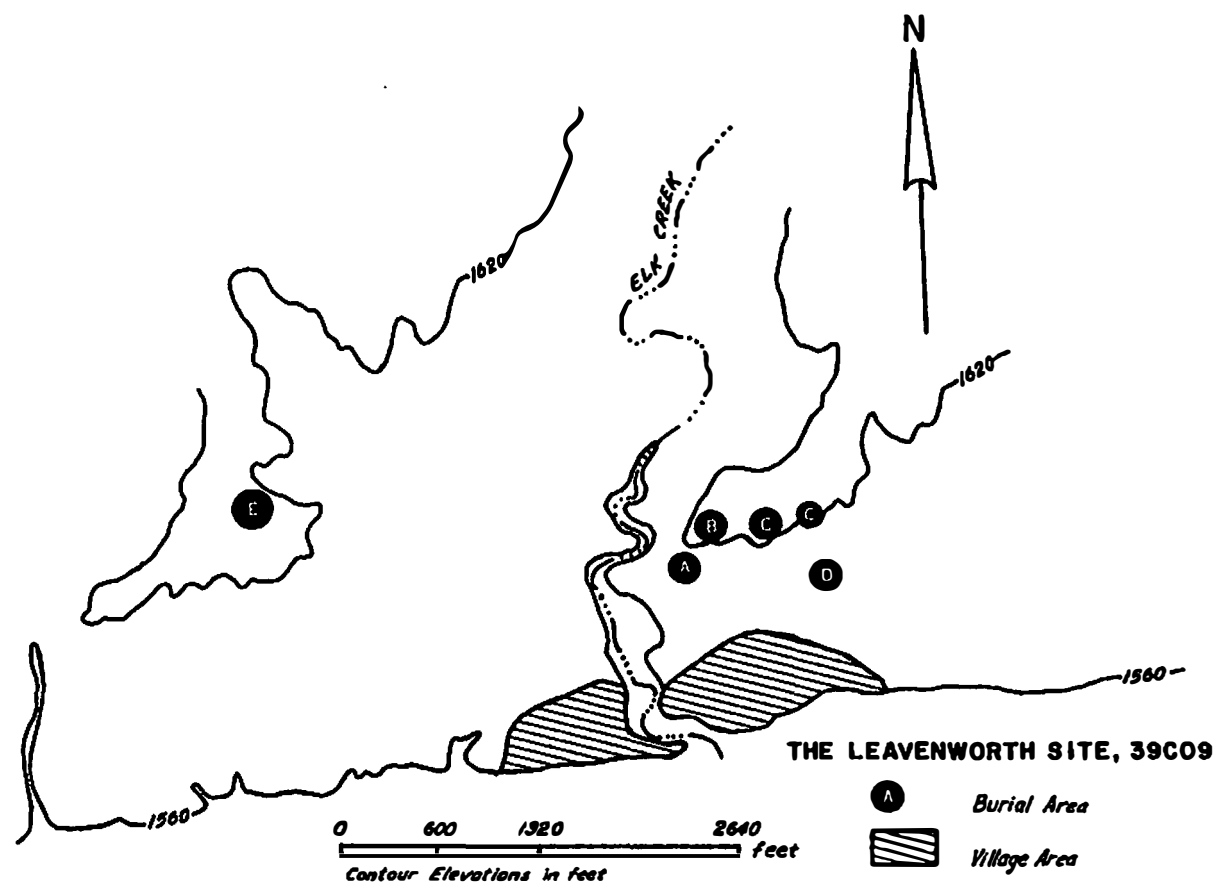


FIGURE 60
Map showing the location of Burial Areas A-E at the Leavenworth site cemetery.

Figure 4.2. Map of Leavenworth site from Bass and coworkers 1971:135

River phase culture (Lehmer 1971). However, an evaluation by Byrd and Jantz (1994) of the ceramic types present in the assemblage from the village areas as reported by Krause (1972) recognized both Le Beau ware and Le Beau S-Rim ware as well as the Stanley Braced Rim ware and Colombe Collared Rim ware associated with Bad River manifestations. This observation lead them to conclude that individuals from both Bad River and Le Beau phase populations occupied the Leavenworth villages. Historic documentation also supports the contention that the villages were occupied by culturally differentiated groups of Arikara. Tabeau noted during his 1804 visit that the Arikara had been previously composed of 18 villages with the remnants of these various groups now occupying the three historic villages. Residing in these three villages, Tabeau recognized 10 different divisions with as many chiefs and dialectic differences among the various divisions (Tabeau in Abel 1939). From the ethnohistoric evidence Parks (1979a, 1979b) concludes that two major dialects were spoken by the inhabitants of the Leavenworth villages which Byrd and Jantz (1994) use to support the hypothesis of two cultural divisions of the Arikara occupying the villages. O'Shea's (1984) study of mortuary practices among protohistoric and historic plains tribes indicates that the burial areas in the Leavenworth cemetery were used by members of culturally distinct groups as an expression of their identity. Studies of craniofacial morphology have demonstrated that differences do exist among the burial areas A, B and C. The majority of the individuals interred in areas A and B are most similar to Le Beau phase populations while most of the individuals interred in area C affiliate with Bad River phase populations (Byrd and Jantz 1994, McKeown and Konigsberg 2000).

Sully (39SL4)

Sully is a multicomponent site consisting of large unfortified village with a cemetery area to the north and northeast of the occupation area located on the left bank of the Missouri River northwest of Pierre, South Dakota (Bass n.d.). In 1930 Bowers excavated 30 burials from the Sully cemetery and in 1957, 1958, and 1961 W.M. Bass directed Smithsonian Institution River Basin Survey crews during excavations that recovered 264 burials (Jantz 1972). An additional 293 burials were excavated in 1962 by a University of Kansas field crew under the direction of Bass (Jantz 1972).

Within the cemetery, four distinct burial areas were identified and designated A, B, D and E (Bass et al. 1971). Based on the presence of European manufactured items at low frequencies, all aspects of the Sully cemetery were originally considered to be early Post-contact Coalescent (Lehmer 1971). However, Jantz (1997) and Key (1983) attribute burial areas A and D to the La Roche phase of the Extended Coalescent variant while assigning burial areas B and E to the Le Beau phase of the Post-contact Coalescent. The temporal variation among the burial areas indicates multiple occupations of the earthlodge village with each group of inhabitants utilizing a separate location in the cemetery. Analysis of cranial morphology demonstrates the presence of variation among the burial areas that may represent temporal differences (Owsley and Jantz 1978). An additional burial area, C, appears to be the remnants of scaffold burials and may be associated with an earlier village located between the Sully site and the Missouri River (Bass n.d.). Figure 4.3 shows the Sully village area and the spatially distinct burial areas in the associated cemetery.

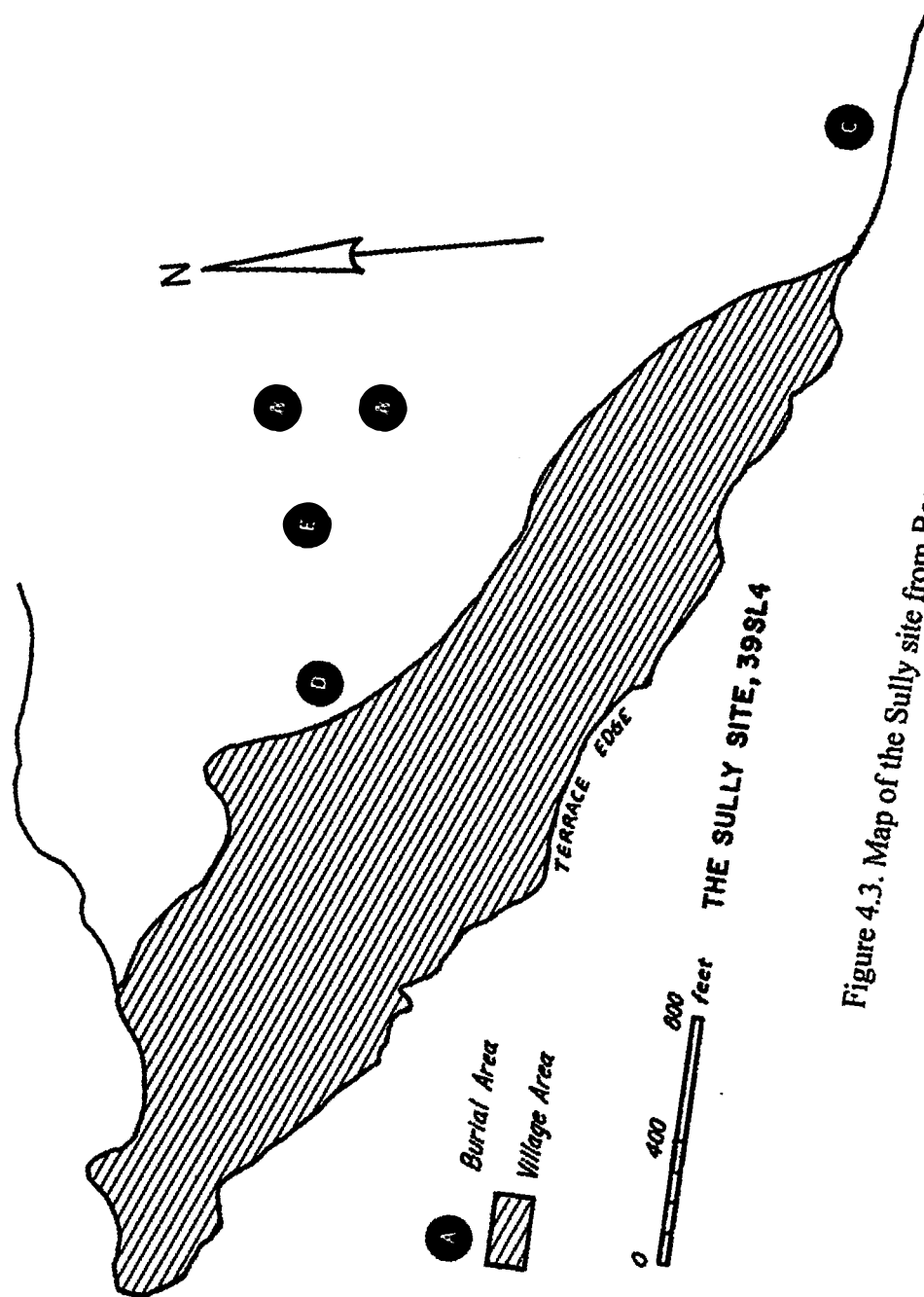


Figure 4.3. Map of the Sully site from Bass and coworkers 1971:136

Cheyenne River (39ST1)

This multicomponent site is located on the right bank of the Missouri River just below the mouth of the Cheyenne River. Of the two proposed occupation periods at this site, the later occupation is attributed to the protohistoric Arikara. W.R. Wedel (personal communication reported in Jantz 1972:24) believes this occupation dates to the end of the 18th century. Excavations were conducted at the site by W.H. Over in 1921 and Wedel in the 1950's with a total of 25 burials recovered (Jantz 1972). Metal and glass artifacts were associated with the burials excavated by Wedel and inhumations covered with slanting wood poles in a manner similar to other mortuary sites attributed to the Arikara were recorded by each investigator (Jantz 1972).

Indian Creek (39ST15)

Indian Creek is a village site with two occupation horizons partially surrounded by a probable defensive ditch located on the right bank of the Missouri River in the Bad-Cheyenne region. The site was investigated in a preliminary nature by the Smithsonian Institution Missouri River Basin Survey (MRBS) in 1948 and 1952 (Lehmer and Jones 1968). During the initial survey two burials were located and excavated by D.J. Lehmer. The burials are attributed to the Bad River 1 phase of the Post-contact Coalescent (Lehmer 1954).

Breeden (39ST16)

Originally known as the Mathison site, Breeden is a multicomponent site on the right bank of the Missouri River 4 miles north of Pierre, South Dakota. Horizons from both the Initial phase of the Middle Missouri Tradition and the Felicia phase of the Post-

contact Coalescent have been recorded at this site with recovered burials being attributed to each phase. The village area encompasses about 25 to 30 acres and the burials were located within the village houses. Excavations that recovered burials from Breeden occurred under the auspices of the MRSB in 1949 and under the direction of R.P. Wheller in 1955 (Brown 1974).

Black Widow Ridge (39ST203)

This site is a village and cemetery located on the right bank of the Missouri River south of the mouth of the Cheyenne River and was originally attributed to the Bad River 1 subphase of the Post-contact Coalescent variant (Lehmer and Jones 1968). A recent evaluation of the artifacts recovered from Black Widow Ridge indicates that this site represents multiple occupations with an Extended Middle Missouri component attributed to the Mandan and a Post-contact Coalescent component affiliated with the Arikara (Billeck 2000, personal communication). At this time the affiliation of the burials is uncertain and there may be burials from each occupation present in the assemblage from this site. However, Black Widow Ridge has traditionally been employed in studies of Arikara and is used in this research while acknowledging possible inconsistencies.

Leavitt (39ST215)

Leavitt is a multi-component site located on the right bank of the Missouri River in the Bad-Cheyenne region. The village area is attributed to the Extended Coalescent variant while items associated with the burials indicate that the larger cemetery is more likely to be Post-contact Coalescent (Lehmer and Jones 1968). Burials were uncovered in 1954 during road construction and the MRBS conducted further excavations during that

year and again in 1955. The cemetery excavated as part of the Leavitt site is also in close proximity to the Post-contact Phillips Ranch site suggesting that the Leavitt cemetery actually may have been used by the inhabitants of the Phillips Ranch village (Lehmer and Jones 1968).

Mobridge (39WW1)

Mobridge is a large multi-component site located on the left bank of the Missouri River near Mobridge, South Dakota. The site consists of a village with a cemetery to the west and south of the occupation area. Excavations were conducted by M.W. Stirling in 1923 and University of Kansas field crews under the direction of W.M. Bass between 1968-1970 and D.H. Ubelaker and T.D. Stewart in 1971. Bass' excavations identified three geographically distinct features in the cemetery area; Feature 1 is located west of the village on a small hill and Feature 3 is situated 100 yards south of Feature 1 on a small knoll; Feature 2 is 200-300 yards south of the village area on a large, long hill (Bass 1970). Burials from all features were recovered under Bass' direction. Additional burials from Feature 2 were excavated during the 1971 field season. Stirling believed that the burials he excavated came from a cemetery "about 300 yards north of the village" (Wedel 1955:86) and therefore have previously been treated as a separate burial feature (e.g. Key 1983). Owsley (1981) has demonstrated that the crania from Stirling's excavations are most similar to crania from Features 1 and 3; however, Billeck (2000, personal communication) contends that Stirling actually excavated 250 yards south of the village in Feature 2.

Differential distribution of European manufactured trade items among the burial areas indicates temporal differences between the features. Few trade goods were recovered from Features 1 and 3 while 20% of the burials excavated from Feature 2 during the 1970 field season contained objects indicative of European contact. While the majority of graves investigated by Stirling lacked any artifacts, the presence of glass beads and a possible copper stain indicates that these burials may date to the Post-contact period (Wedel 1955). Therefore Features 1 and 3 are assigned to the Extended Coalescent and Feature 2 including Stirling's burials are attributed to the Post-contact Coalescent. Craniometric analysis supports the temporal ordering of the burial features (Owsley et al. 1982).

Larson (39WW2)

The Larson site is an earthlodge village with an associated cemetery located on the left bank of Missouri River just south of Mobridge, South Dakota. The protohistoric village is superimposed on an early Woodland horizon and was fortified by a defensive ditch (Bowers 1966). Burials were uncovered in the village area and from the cemetery situated east of the occupation area. Initial investigations by Bowers revealed human skeletal remains inside lodges within the village area (Owsley et al. 1977). Subsequent excavations at the site by University of Kansas field crews under the direction of W.M. Bass occurred from 1966-1968 and over 700 burials were recovered (Jantz 1972:23). European manufactured objects were recovered in substantial quantities from the cemetery burials indicating that they are associated with the Post-contact village occupation (Jantz 1972:24). Owsley et al (1977) provide convincing evidence that the

individuals recovered from the village area were killed during a massacre and represent the terminal occupation of the Larson village.

Swan Creek (39WW7)

Located on the left bank of the Missouri River, Swan Creek is a multicomponent village site with an associated cemetery east of the occupation area. Several graves were excavated by W.H. Over between 1920-1940 (Hurt 1957). W.R. Hurt directed excavations at the site during 1954 and 1955 and identified three occupations of the village area. The earliest of these Hurt (1957) attributes to the Akaska phase of the Extended Coalescent variant. The subsequent two occupations are both assigned to the Le Beau phase (Hurt 1957, Lehmer 1971). Both primary and secondary inhumations were present in the Swan Creek cemetery with some of the secondary pits intruding into the primary burials. Hurt (1957) felt that the primary burials were older than the secondary inhumations attributing them to the earlier Akaska phase. However, the association of a tubular copper bead and a glass bead with two of the primary burials (Hurt 1957) indicates that both burial types might be attributed to the later Le Beau phase occupation (Owsley et al 1981). Analysis of crania from Swan Creek indicate that the burials represent a heterogeneous group and some Mandan individuals may be present (Owsley et al 1981).

Landmarks

A series of 40 landmarks found on the face and vault of the human cranium was identified for the purposes of this study. Table 4.3 provides a list of these landmarks and

Table 4.3. List of landmarks employed.

Landmarks	
1. prosthion	22. midfrontal
2. subspinale	23. left frontotemporale
3. nasion	24. right frontotemporale
4. left dacryon	25. bregma
5. left frontomolare anterior	26. left pterion
6. left posterior frontomolare	27. left superior zygotemporale
7. left ectoconchion	28. left inferior zygotemporale
8. left zygoorbitale	29. left zygomatic root
9. left zygomaxillare anterior	30. left asterion
10. right dacryon	31. lambda
11. right frontomolare anterior	32. midparietal
12. right posterior frontomolare	33. right asterion
13. right ectoconchion	34. right zygomatic root
14. right zygoorbitale	35. right superior zygotemporale
15. right zygomaxillare	36. right inferior zygotemporale
16. left alare	37. right pterion
17. right alare	38. basion
18. left M1	39. opisthion
19. left M2/M3	40. posterior occipital
20. right M1	
21. right M2/M3	

definitions for landmarks can be found in Appendix A. The location of all landmarks visible from a left lateral view are shown in Figure 4.4. Many of the landmarks are traditionally defined landmarks that have been used as endpoints for the linear measurements associated with craniometrics. The non-traditional landmarks have been identified by other researchers or by myself in order to more adequately cover the geometry of the face and vault. Some of the non-traditional landmarks approximate the position of traditional caliper defined landmarks. For example, M2/M3 (a point on the lateral alveolar crest between M2 and M3) was identified as an approximation of ectomolare which is the endpoint for maxillo-alveolar breadth and is defined as “the most lateral point on the lateral surface of the alveolar crest” (Moore-Jansen et al. 1994:45). The traditional landmark ectomolare tends to fall around the second molar; however, its position can “move” along the alveolar crest from individual to individual. These new landmarks are identified without the use of calipers and the more precisely defined locations are more likely to be consistent from individual to individual, thus representing homologous landmarks.

Criteria for Landmark Selection

Landmarks were chosen based on their coverage of the biological form (the cranium) and the need for homologous points. As previously mentioned, most of the landmarks employed in this study have been used as endpoints for commonly collected linear distances. Since craniometrics and geometric morphometry share the common goal of capturing information regarding size and shape from the form under investigation,

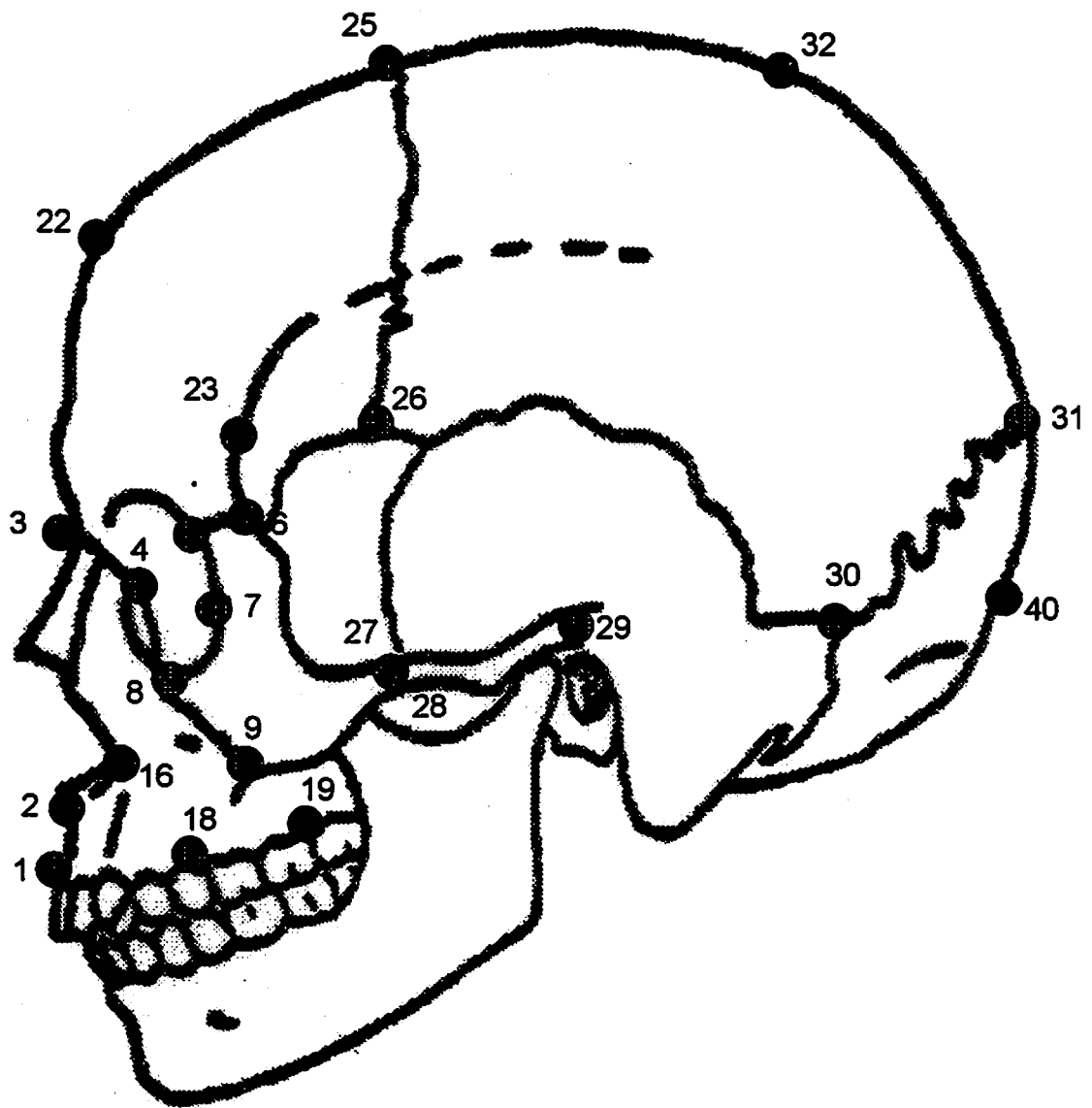


Figure 4.4. Lateral view of cranium with visible landmarks labeled.

these traditional points are included to ensure that these important dimensions are incorporated into each configuration.

Bookstein (1982, 1986, 1990, 1991) describes morphometry as a fusion of geometry and biology. In particular, morphometry blends information from geometric location and biologic homology. In biological terms, homology describes the ontogenetic or functional correspondence between morphological features or elements among individuals or across species. As landmarks represent geometric locations they should also reflect biologic homology – in other words, the location of the landmark must contain valid biological information about the same aspect of the form from individual to individual. According to Bookstein (1986, 1990, 1991) there are different types of landmarks that can be collected from biological forms. Bookstein (1990, 1991) defines three different types of landmarks and the appropriateness of each type for landmark based investigations is discussed. Type 1 landmarks are “recognizable points on boundaries between regions of distinct histology” (Bookstein 1990:215). These landmarks are generally defined by the intersections of sutures and/or other distinct boundaries such as the edge of the orbit. Examples of Type 1 landmarks are nasion, bregma, pterion and zygoorbitale. Bookstein (1990, 1991) considers this type of landmark to be the most useful and informative as they are true homologues. Type 2 landmarks are “local geometric features of extended tissue boundaries” (Bookstein 1990:215) such as the deepest incurvature or the greatest extension along a curve. Some examples of Type 2 landmarks are the most medial point along the temporal line (frontotemporale) and the most lateral point along the frontomale suture (frontomale posterior). While these

landmarks are not as informative as Type 1 landmarks, they do contain important biological information and are more useful than Type 3 landmarks which represent extremal points along a linear dimension of the form (Bookstein 1990, 1991). Basically these are endpoints for the maximum measurement along a linear axis. Examples of Type 3 landmarks include opisthocranium (posterior endpoint for maximum cranial length, not used in this study) and eurion (endpoint for maximum cranial breadth, not used in this study). Bookstein (1991:65) describes these type of landmarks as “rarely meaningful” and “deficient” since only one of their coordinates contains pertinent information, namely size. The other coordinates provide little biological information as they tend to vary randomly.

The traditional landmark which represents the endpoint for maximum cranial breadth, eurion, was not used in this study due to the high degree of variation in its location from individual to individual. An analysis of variance (ANOVA) on the landmark residuals, or distance from the landmark mean after a Procrustes fitting, from 139 crania from the Larson site (39WW2) indicates that the variability for eurion significantly exceeds that of any other landmark, perhaps except posterior occipital. Figure 4.5 generated by GRF-ND (Slice 1994) illustrates the range of anterior-posterior and medio-lateral variation for each landmark after the Procrustes fit and shows how only one coordinate (or direction) for eurion contains any valid biological information. The breadth information is fairly consistent as evidenced by the relatively minimal medio-lateral variation while the residuals vary randomly in the anterior-posterior and inferior-superior (not evident in the two dimensional figure) directions. As an endpoint

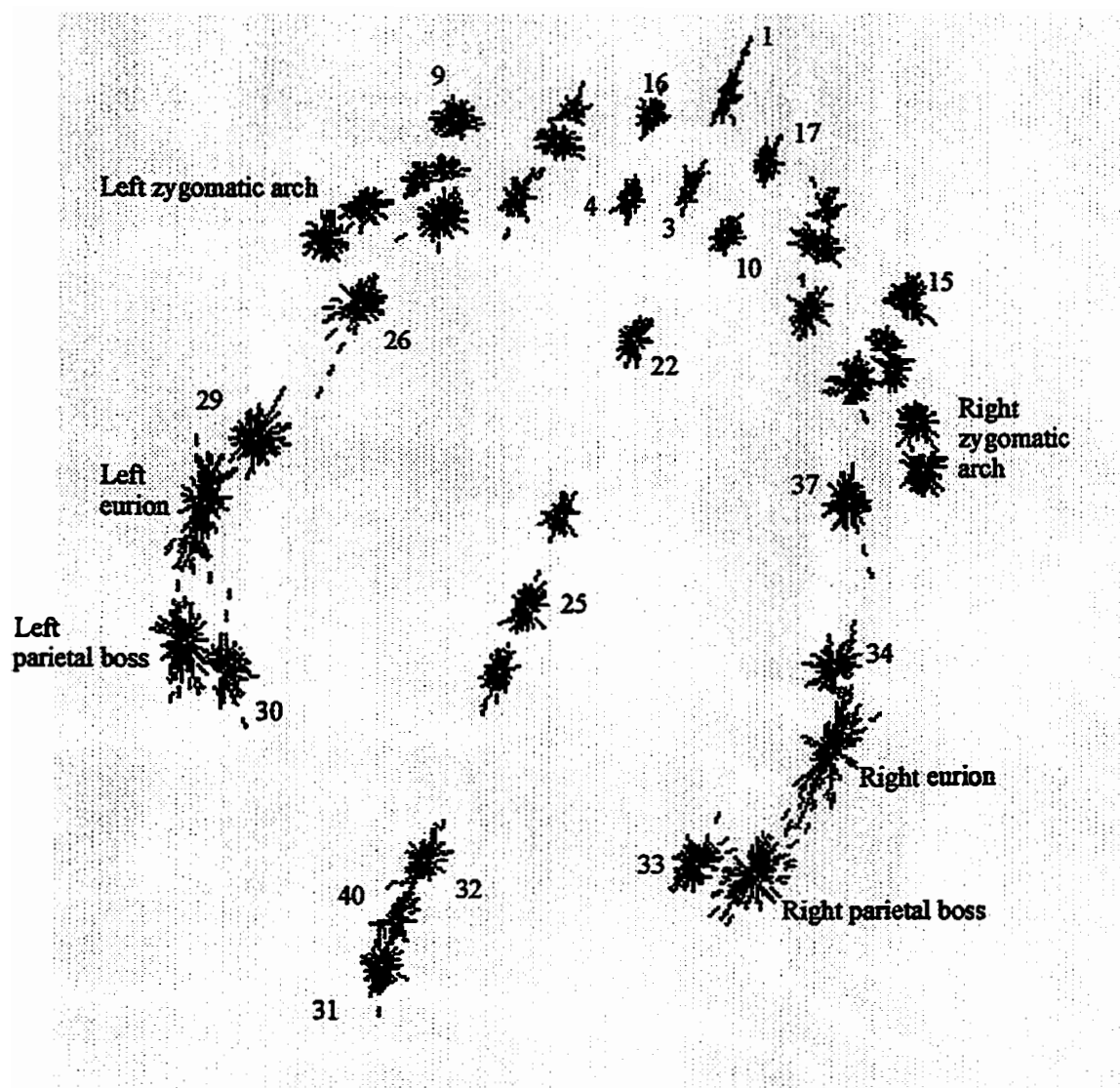


Figure. 4.5. Landmark scatter for eurion and the parietal bosses. This is a superior view shows all landmarks including those from the inferior aspect of the cranium. Anterior is to the upper right corner.

for maximum cranial breadth, eurion is a caliper defined landmark. There may be more than one set of endpoints on any cranium where the linear distance across the cranial vault is maximized which probably contributes to the greater variability. While the linear measurement, maximum cranial breadth, is an important variable in traditional craniometric studies, the excessive variation in the location of eurion makes it a poor landmark for use in landmark based investigations and it has been excluded for that reason. A correlation analysis using craniometric data collected by W. W. Howells from 30 world populations demonstrated that biasterionic breadth is significantly correlated with maximum cranial breadth for all populations except for the North and South Maori. While the correlations are not large (R ranges from 0.39 (Anyang) to 0.739 (Ainu); $p < 0.01$), they do indicate that the asterions reflect some of the same information about cranial breadth that is found in the eurions.

Repeatability

Repeatability of landmark identification was evaluated by a Model II ANOVA employing residuals from each of the 40 landmark coordinates recorded on 29 crania at two different times. The $(29 \times 2 =) 58$ configurations were fitted via Procrustes analysis removing differences due to translation, rotation and scaling. The square root of the sum of the squared residuals from the fitting was used as a measure of distance from the landmark mean for each landmark. The Model II ANOVA is designed to assess the relative contribution of factors to the overall variation present in the model. In this instance, variation across a landmark could be due to differences in landmark placement

between data collection events (lack of repeatability) or variation in landmark position across individuals. For each landmark both time (1 versus 2) and individual were included as independent variables in the model. Differences among the individuals is expected to contribute significantly to the variation present in the model. If time is also a significant contributor to variation in the model, this would indicate a lack of repeatability for this landmark. The ANOVA was conducted using SAS (1996).

The results of this study indicate that only bregma, right superior zygotemporale and right inferior zygotemporale are significantly different ($p < 0.01$) across the repeated measures. The variation in placement of landmarks along the zygomatic arch is of little concern since these landmarks are absent bilaterally at a relatively high frequency and are removed from all analyses subsequent to the Procrustes fitting. The variation in the placement of bregma does present some problems and will be taken into account for interpreting results related to variability at this landmark.

Collection Protocol

All observable Cartesian (x, y, z) coordinates were collected from each cranium in the sample via a MicroScribe-3DX, three dimensional digitizer, connected to a laptop computer. Observation of landmarks on crania occurred according to two different collection protocols. The first collection method was employed early in the data collection process and was used for all crania housed at the Smithsonian Institute. The second collection protocol was implemented later in the collection process and was utilized for all crania housed at the University of Tennessee, Knoxville.

The first data collection protocol involved collecting landmarks from a single cranium as two separate configurations. Each configuration was saved as a page in an Excel spreadsheet and each case was saved as an Excel spreadsheet file. A series of landmarks was observed on the superior aspect of a cranium secured to a stable surface with modeling clay. A smaller, second series of landmarks was collected from the inferior aspect of the cranium while it was secured with modeling clay to a stable surface in an inverted position. The MicroScribe-3DX and data collection from the inverted cranium is shown in Figure 4.6. At least 3 and as many as 7 landmarks were observed from both the superior and inferior perspectives. These landmark coordinates served as “matching points” for the rotational procedure that fitted the two configurations together. This program, known as GIT (Get It Together) written by Lyle Konigsberg, uses a Procrustes procedure to translate and rotate the two configurations until the sum of the squared distances between “matching points” is minimized. Thus the two configurations are brought together and the landmarks are output as a single configuration.

The second data collection protocol employed in this research used a vertical metal stand with a perpendicular metal ring to elevate the cranium allowing access to all aspects of the form during landmark observation. Figure 4.7 depicts the arrangement utilized for this data collection procedure. The three dimensional coordinate data collection program, 3Skull, written by Stephen Ousley, generates two Paradox databases, one containing the *x*, *y* and *z* landmark data and a second with the traditional Howells (1973) craniometric data set. This data collection procedure produces a set of three dimensional landmarks comprising a single configuration for each individual.

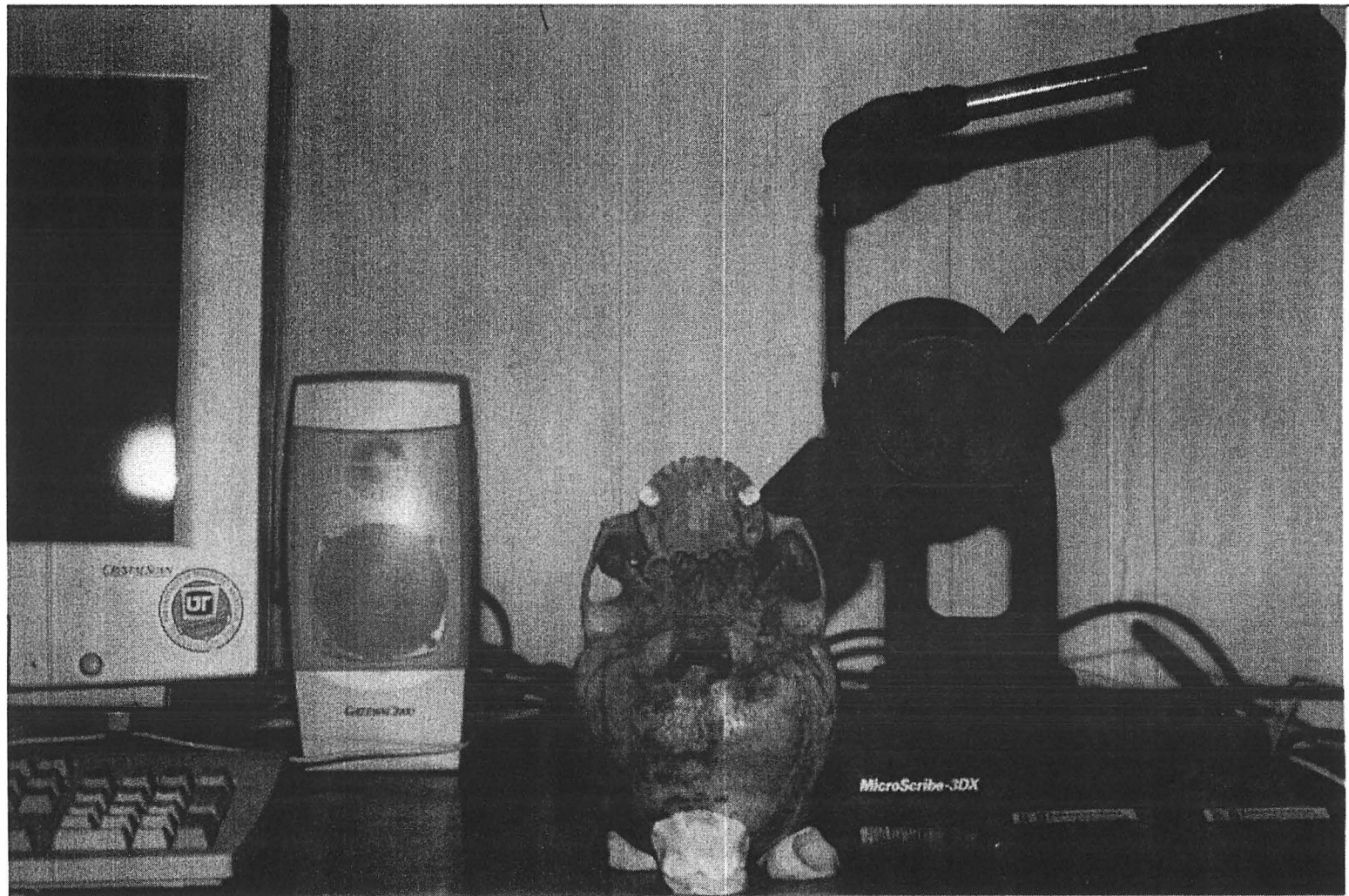


Figure 4.6. Data collection employing the MicroScribe-3DX

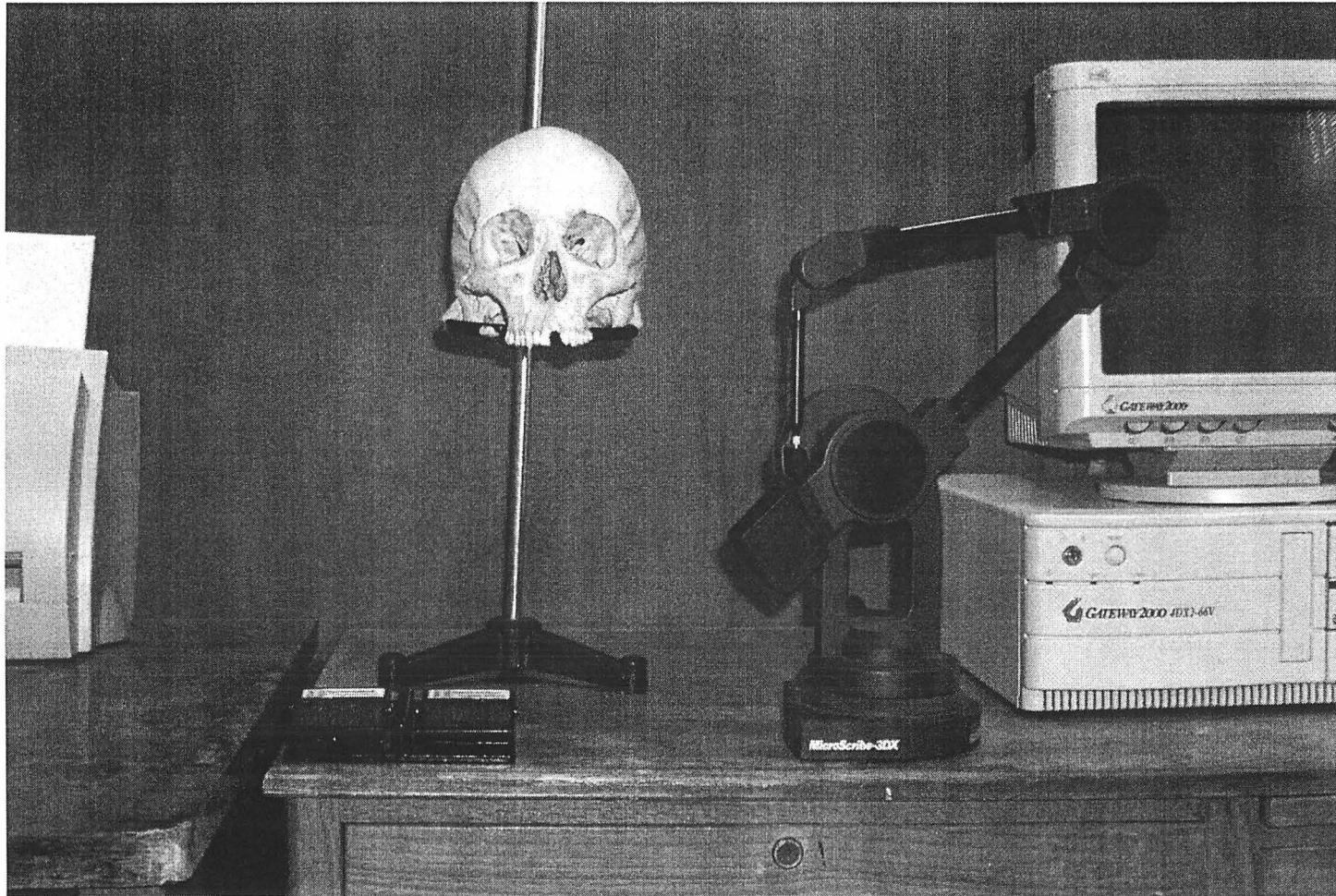


Figure 4.7. Data collection employing the MicroScribe-3DX and a stand to elevate the cranium.

Missing Landmarks

As is true of much human skeletal material from an archaeological context, incomplete, fractured, cracked and warped crania are present in this series rendering some landmarks unobservable. In the case of incomplete crania or crania with missing elements (such as the zygomatic arches, etc), landmarks were not present and could not be collected. In some instances, perimortem trauma and/or postmortem cracking and warpage displaced landmarks such that they are no longer appropriate for collection and analysis purposes. Occasionally when the data collector (me) felt like a reasonable estimate could be obtained, the landmark's position was estimated for collection purposes. However, this was done sparingly.

Missing bilateral landmarks were estimated by mirroring across the midline of the configuration. This was accomplished with a program called SAM3.0 written by Lyle Konigsberg. SAM (Smoke And Mirrors) rotates the configuration until three specified landmarks (generally nasion, bregma and lambda) form a midline plane with one point (generally nasion) at 0,0,0. The integrity of the configuration is maintained during these rotations; the configuration is simply being rotated into a known coordinate system where the three specified landmarks along the midsagittal plane are at zero on the medio-lateral axis (which in this case is the z axis). Missing bilateral landmarks with an antimere present are simply mirrored across the midline. In this process the x (anterior-posterior) and y (superior-inferior) coordinates remain the same and the sign (+/-) of the z coordinate is simply changed.

CHAPTER 5

ANALYTICAL METHODS

Investigation of cranial shape variation among individuals attributed to the Arikara tribe combines traditional statistical analyses with tools of geometric morphometry. Extensive work has been done on the population affinity of the individuals from the various sites under investigation; therefore, emphasis here is on the new information that can be gleaned from the landmark based methods. Specifically, this research tests the hypothesis that variation in cranial morphology among the Arikara is patterned across time and space. If such a pattern exists and can be established as suggested by previous craniometric research, the exact nature of the morphological variation can be identified and interpreted. To this end, principal component scores based on the residuals from a Procrustes fitting of landmark based configurations are used in traditional univariate and multivariate analyses to construct a framework based on the patterns of intersite relationships. A landmark based method, thin-plate spline analysis, is then applied to two dimensional mean configurations to investigate the overall patterning in cranial shape variation.

This is accomplished by a series of analytical procedures beginning with a Procrustes fitting of all 522 three dimensional configurations consisting of 40 landmarks each, followed by principal component analysis conducted on the Procrustes residuals. Principal components that contribute to our understanding of morphological variation were “visualized.” The eigenvectors for the principal components are scaled and added

to the overall consensus configuration generated by the Procrustes fitting. These hypothetical specimens represent the morphological variation along each principal component and are plotted. The first 39 principal components representing 90% of the within sample variation are then employed in subsequent traditional statistical analysis in order to establish a framework within which to interpret the shape variation. The principal components are utilized for canonical analysis and for regression analysis. The biological distance matrix generated by the canonical discriminant procedure is used in conjunction with temporal and geographic distance matrices to perform Mantel tests looking for correspondence between the distance matrices. Overall patterns of morphological variation are examined via thin plate spline analysis, a geometric morphometric tool for investigating the nature of morphological differences between two configurations. In this instance, mean configurations were generated via Procrustes superimposition and these two dimensional configurations are compared in pairwise manner within the framework of population relationships previously established.

Superimposition or Procrustes Fitting

The coordinates for each configuration as collected via the MicroScribe-3DX digitizer exist in an arbitrary coordinate system relative to the origin point in the base of the digitizer. These configurations exist in figure space with pk dimensions where each of the p landmarks is represented by k coordinates (Rholf 1996). Since I collected three dimensional coordinates for 40 landmarks, the figure space for the cranial configurations has $(40 \times 3 =)$ 120 dimensions. In order to investigate the shape differences that exist

among the configurations, the differences due to location within the figure space, rotation and scaling (size) must first be removed. Full generalized Procrustes analysis (GPA) accomplishes this goal by translating, scaling and rotating the configurations to minimize the sum of the squared differences across homologous landmarks. Translation brings all configurations into a common figure space by centering them on a shared origin or centroid, rotation puts all configurations in a common orientation so that all the landmarks coincide or “match up” and scaling removes the size differences by achieving a unit centroid size (Rholf 1996). Specifically GPA employs the model

$$X' = \rho XH + 1\tau$$

where X' is the fitted configuration as a result of scaling X by ρ , rotating X by H and translating X by τ (Slice 1996:181). In this model both X and X' are $p \times k$ matrices of the k coordinates for the p landmarks in the pre- and post-fitting configurations, “ ρ is a scalar, H is a $k \times k$ transformation matrix, 1 is a $p \times 1$ matrix of ones and τ is a $1 \times k$ matrix of translation parameters” (Slice 1996:181). A reference specimen denoted by Y , a $p \times k$ matrix, is employed to initially estimate these parameters.

Once the objects are translated, optimally rotated and scaled, the object can then be understood as a point in Kendall’s (1984) shape space which has $pk - k - k(k-1)/2 - 1$ dimensions. This space is non-Euclidean in nature and for three points in two dimensions, the space “can be visualized as the surface of a sphere” (Rholf 1996:119) where each configuration corresponds with a point on the sphere’s surface. For three or more dimensions, this space becomes increasingly more complex. Due to the non-

Euclidean and highly complex status of this space, statistical analyses cannot be conducted here. However, for each configuration that exists in Kendall's shape space a projection can be made into a linear vector space that is tangent to the shape space. Appropriately termed tangent space, this space has Euclidean geometry and intersects with the shape space at a point that coincides with the Procrustes consensus (Rholf 1996). Full Procrustes residuals or the difference between the fitted configuration and the consensus after translation, rotation and scaling from a least squares fitting approximate tangent space coordinates and can be used for statistical analyses of shape variation among configurations.

Since GPA involves scaling, the size related sexual dimorphism is removed permitting pooling of the sexes for each site. However, some shape related dimorphism may still be present, a factor which should be accounted for in subsequent analyses.

General Procrustes analyses are carried out using the Generalized Least Squares (GLS) procedure in GRF-ND (Slice 1994). The GLS procedure utilizes an iterative procedure to fit multiple configurations to a consensus. Unless another reference object is designated, the first configuration read is employed as the reference configuration and all subsequent configurations are translated, scaled and rotated to optimally minimize the sum of the squared differences as described above. After all configurations have been fit to the initial consensus, a new consensus is derived by taking the average of all the fitted configurations. During the second iterations all configurations are fitted to the new consensus form and the difference in fit between the first and second iterations is calculated. If this difference is small enough, the iterations will cease; if not, a third

iteration proceeds using the new consensus form. The iterations cease when the difference between the new and old “consensus” configuration conforms to some standard (Slice 1994).

Potential outliers are identified during the fitting process. Configurations are fitted by site and the residual rays plotted by GRF-ND (Slice 1994) allow for the identification of outliers as they will be located outside the cluster representing the normal residual variation at that landmark. Outliers are due to incorrectly observed landmarks and estimated landmarks mirrored across a “wobbly” midplane where one or more of the landmarks assigned to create the midplane do not actually occur in the midline of the configuration. Coordinates that are associated with observer error are deleted and replaced with the missing data code. If these are bilateral landmarks with a present antimere, they are estimated by mirroring across the midplane. For mirrored landmarks which appear to exceed the normal range of variation even though the location of the observed antimere does not, an attempt was made to correct the midplane wobble by selecting other landmarks for the purposes of creating the midplane. Sometimes this process corrected the problem and sometimes it did not. In the latter instance, the estimated coordinates are deleted and replaced with the missing data code.

After identifying and correcting problems associated with outlier coordinates, the individual site files are appended to one another and all configurations were subject to generalized Procrustes analysis. The GLS procedure in GRF-ND (Slice 1996) was employed to superimpose all configurations. Useful output generated by this process includes Procrustes fitted coordinates for the each configuration which can be utilized for

plotting, a consensus configuration across all configurations and Procrustes residuals for each coordinate of each configuration. While general resistant fit (GRF) methods may provide a better fit for configurations where shape differences tend to be primarily localized differences and GRF is an option found in GRF-ND, residuals generated by GRF fitting cannot be used for statistical analyses. In explanation, Bookstein (1996) states that the sum of squares for residuals from GRF procedures do not agree with the corresponding Procrustes distance which is the only statistically valid measure of shape distance for landmark data. In other words, the resistant-fit residuals do not exist in the linear space tangent to Kendall's shape space and, therefore, do not approximate tangent coordinates.

Principal Component Analysis and Interpretation

Principal component analysis seeks to maximize the within sample variance of a linear combination of variables. This results in dimensions or axes along which the observations are maximally dispersed or spread out (Rencher 1995). Since no *a priori* group is assumed, the variance measured is for the entire sample. The axes along which observations are spread may also reflect biological variation when working with data regarding the dimensions of an organism (Reyment et al. 1984). The component scores are organized such that the component representing the largest amount of within group variance is first, the second, which is orthogonal to the first, contains the next greatest percentage of within sample variation and so on. This serves to reduce the dimensionality of the data concentrating the most variation in the first several components.

The principal component scores themselves can be used to investigate within and between group variability. The scores can also be used as variables in other types of multivariate analyses as they provide a summary of the variability present in the sample under investigation. This can be an important consideration when working with extremely large data sets such as those associated with three dimensional data.

Principal component analysis of the covariance matrix of the Procrustes residuals, which approximate tangent space coordinates, accomplishes several important goals. First, it directly utilizes the information about shape variation and presents that information in the form of principal component scores which can be interpreted visually. Secondly, and just as importantly, it reduces the dimensionality of a potentially enormous data set so that most of the within sample variation is concentrated in the first few components and a series of components represent the vast majority of variation present in the overall sample. The components can be directly employed to assess morphological variability or they can be used in subsequent statistical analyses as variables that summarize the variation present in the sample under consideration.

Principal component analysis is conducted on the covariance matrix of the Procrustes residuals for 29 landmarks using SAS (1996). Due to relatively high frequencies of absence, the landmarks prosthion, left and right M1, left and right M2, inferior and posterior zygomatic arch points from both sides and opisthion were eliminated from the statistical analysis. Any individuals with missing data were not considered in the SAS statistical computations reducing the sample total to 453 individuals. In accordance with the dimensionality of the shape space ($3k-7$ for three

dimensional data), 80 eigenvalues were generated for the extraction of an equal number of corresponding principal components with their associated eigenvectors. Principal component scores were calculated for each individual and were output as a data set for subsequent analysis.

An ANOVA (univariate analysis of variance) was conducted also using SAS (1996) to assess differences in group means for each PC. Since this involved 39 univariate tests, a Bonferonni correction was applied to the alpha for tests of significance ($\alpha = 0.05/39 = 0.001$). Principal components that were significantly different across the groups for their mean values were identified and investigated for the morphological meaning associated with the variation.

In order to visualize the morphological variation along a principal component axis, the eigenvectors of the principal component must be put into configuration space. This is accomplished by uniformly scaling the eigenvectors for each coordinate by an appropriate factor and adding the product to the coordinates of the consensus or mean configuration (Dryden and Mardia 1998, Slice 1996). This creates a hypothetical configuration which represents the morphological patterns associated with a score along one principal component axis while all other principal component scores are equal to zero. This hypothetical configuration will never accurately represent the morphology of any particular specimen, but it illustrates the morphological variation captured by that principal component. I scaled the eigenvectors for each principal component of interest by factors of +0.01 and -0.01 producing forms for the positive and negative extremes along that principal component. These hypothetical specimens are plotted using the three

dimensional viewer, 3DV2.5 (Garcia 1992) from which two dimensional plots are derived for presentation purposes. These plots visually depict the variation permitting interpretation of the morphology represented by the principal component.

Regression Analysis

Manly (1995:148) notes that “the regression coefficient for a simple, linear regression is an equivalent test statistic to the correlation coefficient.” Since it was hypothesized that some of the variation in morphology among the groups could be accounted for by variation in time and/or geography, it is appropriate to use multiple regression to test the significance of correlations between independent variables such as median site date, centroid latitude and centroid longitude and the dependent variables, the principal components. Therefore, multiple regression is employed to regress group mean principal components on each of the independent variables, time, latitude and longitude using the randomization program, RT, written by BFJ Manly (1997). The correlations generated by the regression are tested for significance by randomizing the independent variable 1000 times and then computing a *t*-statistic which determines what percentage of the randomized coefficients exceed the observed coefficient.

Each of the 39 mean principal component scores is regressed on each of the independent variables, time, latitude and longitude. The independent variables are randomized for 1000 runs and significance was assessed via a *t*-statistic. Principal components significantly correlated with either time or geography are identified and the morphological import of the variation is interpreted.

Canonical Analysis

Canonical analysis derives linear combinations of variables that best reflect the variation present between the groups under investigation. By finding the dimensions along which the spread for these variables is greatest, the method reduces the dimensionality of the group differences such that they can be depicted in one, two or three dimensional space, depending on how much variation is accounted for by each canonical variate. The discriminant functions serve to effectively separate the groups and the efficacy of the ability to correctly allocate individuals to their group can be tested providing information about the actual degree of differentiation. The greater the differences, the better the allocation procedure should work and vice versa. Overall differences between groups is summarized by the generalized distance of Mahalanobis (1936). However, in instances where a large number of groups is being compared, these pairwise comparisons can be difficult to interpret. Plotting along the canonical variates can help elucidate the similarities and differences among the groups, especially when the variables that contribute to each canonical axis are taken into account.

A data set consisting of 39 principal component scores for each individual was subjected to canonical discriminant analysis for the detection of group differences and calculating a generalized distance matrix using SAS (1996). A cross-validation or jack-knife procedure tested the efficiency of the linear discriminant functions for allocating individuals to their respective groups. The canonical option was executed generating $N(\text{number of groups})-1$ canonical variates from which interpretative plots are derived.

Distance Matrix Correlations (Mantel tests)

While the linear regression analysis described above identifies principal components that are correlated with time and/or geography component by component, correlations between distance matrices provides information about the correspondence in overall variation for different sources of variability. The Mantel test as developed by Mantel (1967) and generalized by Manly (1986) and Smouse et al. (1986) is particularly appealing for testing the correspondence between two and three distance matrices. Based on a general regression model, this approach measures the correlation between corresponding members of the distance matrices and determines the significance of such correlations by randomly permuting the order of the elements in one of the matrices (Manly 1997). Specifically, significance is assessed by determining how many of the comparisons involving a randomly rearranged matrix produce a correlation value as larger or larger than the observed correlation (Smouse and Long 1992).

Both Smouse et al. (1986) and Manly (1986) consider the multiple Mantel test where two different distance matrices in concert may help explain the variation present in a third distance matrix. For the biological sciences, the obvious examples here would be the variation present in a biological or genetic distance matrix and how it may be related to variation in spatial (geographic), environmental or temporal distance matrices. This type of three way comparison can be accomplished by assuming the following multiple regression relationship

$$g_{ij} = \beta_0 + \beta_1 s_{ij} + \beta_2 e_{ij} + \varepsilon_{ij}$$

where g_{ij} , s_{ij} and e_{ij} represent the three matrices containing the distances between elements i and j , β_1 is a measure of the relationship between g_{ij} and s_{ij} taking into account any effects related to e_{ij} , β_2 is a measure of the relationship between g_{ij} and e_{ij} taking into account any effects related to s_{ij} , and ε_{ij} represents any independent error (Manly 1995:180). Significance for the observed correlations is tested by permuting elements of the dependent matrix (g_{ij}) looking for correlations at least as large as the observed.

For the purpose of understanding the relationship between variation in the biological distances between Arikara sites and the temporal and geographic distances between the sites, Mantel tests were employed. The generalized distance matrix generated by the canonical discriminant procedure representing the biological distance between each pair of sites was compared to geographical and temporal distance matrices using the Mantel test methodology. The temporal distance matrix was produced by calculating the difference between median site dates on a pairwise basis. The geographic distance matrix was developed from the direct distance from the center of one site to the center of another site. The distances are based on latitude and longitude for each site (Key 1983) and were calculated on a pairwise basis using an algorithm that takes into account the earth's curvature. Each of the distance matrices employed were symmetric matrices of equal dimensions.

Using a TRUEBASIC program written by RL Jantz, the biological distance matrix was compared to each of the geographic and temporal distance matrices in a pairwise manner. Then a three-way comparison was performed where either the geographic or

temporal matrix was held constant while the other matrix was compared to the biological matrix. Each test was randomized 500 times and the significance of the correlation was evaluated by the number of randomizations where the randomized correlation equaled or exceeded the observed correlation.

Thin-Plate Spline Analysis

The thin-plate spline (TPS) as a tool for investigating biological shape variation was introduced in Bookstein's 1989 "Principal warps: Thin-plate splines and decomposition of deformations" as a way to mathematically generate the transformation grids that D'Arcy Thompson had promoted in 1917. By using a smooth function such as the thin-plate spline, a target configuration can be deformed onto a reference configuration and the shape variations present between the two specimens can be mathematically measured and visually appreciated. The thin-plate spline model is borrowed from continuum mechanics where the spline is a thin metal sheet that is constrained at some points but otherwise free to follow the shape that minimizes the energy necessary to bend the metal sheet (Slice et al. n.d.). This type of deformation involves both affine (or uniform) shape change and non-affine (or localized) shape change. The resulting interpolation can be visualized in terms of a Thompson style

transformation grid. For two dimensional landmarks, the thin-plate spline function is

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = A \begin{bmatrix} 1 \\ x \\ y \end{bmatrix} + \sum_{j=1}^p \mathbf{n}_j U(r_j)$$

where x and y represent the coordinates of any landmark on the reference, x' and y' are the resultant coordinates of the point in the space of the target specimen, A is a $k \times (k+1)$ matrix of parameters specifying the affine transformation which includes translation, rotation, scale and shear, “ $U(r_j)$ is the function $r_j^2 \ln r_j^2$,” r_j represents the distance “between a point (x,y) in the space of the reference and the j th landmark in the reference,” and the $\mathbf{n}_j$ are the k -dimensional vectors of parameters for the non-affine component of the space deformation (Rohlf 1996:120).

The affine or uniform component describes universal change for the configuration caused by translation, rotation, scaling or shearing. While the first three types of affine change have already been described in the discussion of Procrustes analysis, shear has not been previously described and it represents the only shape change component of affine transformation. Shear corresponds to uniform compression or stretching along a particular axis (Rohlf 1996). The non-affine components of change are localized regions subject to compression, expansion, bending, etc. by the transformation.

Thin-plate spline analysis was employed for pairwise comparisons of mean configurations across grouped sites and for pairwise comparisons of mean configurations by site as warranted by the overarching framework of intersite relationships. Consensus configurations for each site and for grouped sites were computed by superimposing all configurations for each site or group

of sites using the GLS procedure in GRF-ND (Slice 1994). The program Thin-plate spline (Rohlf 1997) was employed for generating the thin-plate spline deformations and their plots, the transformation parameters, and the Procrustes distance between the two configurations. In conjunction with the TPS graphs, lateral view wireframe plots illustrate static differences between the mean configurations for sites and grouped sites. This endeavor should elucidate the overall pattern of variation that is reflected by the statistical analyses of the Procrustes residuals via visual and statistical results.

CHAPTER 6

RESULTS

Very early in the analysis phase of this research it became evident that the two crania from the Breeden site (39ST16) are extreme outliers when compared to the other 17 sites considered. Principal component plots indicate that the morphological pattern exhibited by the Breeden crania is quite unlike that of the other Arikara crania. Considering the archaeological context from which these crania were recovered, pit burials within the confines of a lodge, it is quite probable that they are not closely related to the other samples in this study. Therefore, the two crania from Breeden were eliminated from the original landmark data set.

Additionally, the landmark, posterior occipital, was noted to exhibit greater variability in location than many of the other landmarks. This is a point of some concern because of the different methods used to observe this landmark with the two collection protocols employed. For the crania housed at the Smithsonian, this landmark was observed from an inferior position; however, it was generally observed as occipital subtense on the crania located at UTK. Plots illustrating the morphological variation represented by principal component 1 (PC1) demonstrated that this landmark had a much greater range of variation than any other landmark and that it was patterned along an inferior-superior axis. Examination of the eigenvectors for PC1 indicate that this landmark was contributing disproportionately to the overall principal component. It was feared that the differing modes of collection for this landmark could account for the

inferior-superior nature of its variation. Using a questionable landmark that was contributing considerably to the overall structure of the principal components seemed a dubious proposition and the landmark was eliminated from all analyses subsequent to the Procrustes fitting except for the thin-plate spline analysis.

These two actions resulted in the Procrustes fitting of 520 configurations each consisting of 40 landmarks for 17 groups. All subsequent analyses except for the thin-plate spline were conducted on data from 29 landmarks for 452 configurations. Mean configurations consisting of 36 landmarks were employed for the thin-plate spline analysis of overall shape variation. Both left and right bilateral landmarks are included in the two dimensional configurations with only the landmarks of the zygomatic arch removed.

Procrustes Analysis

All 520 configurations were successfully fitted after three iterations of the general least squares (GLS) procedure in GRF-ND (Slice 1994). Figure 6.1 depicts the location of the landmarks for all configurations as they exist in figure space after they have been brought into a common coordinate systems by SAM. Note that these configurations are still in figure space because they have not been centered on the origin or centroid which is required for preform space. Figure 6.2 displays the location of the landmarks for all configurations relative to the consensus configuration after Procrustes fitting via the GLS procedure in GRF-ND (Slice 1996). The cloud of points around each consensus location

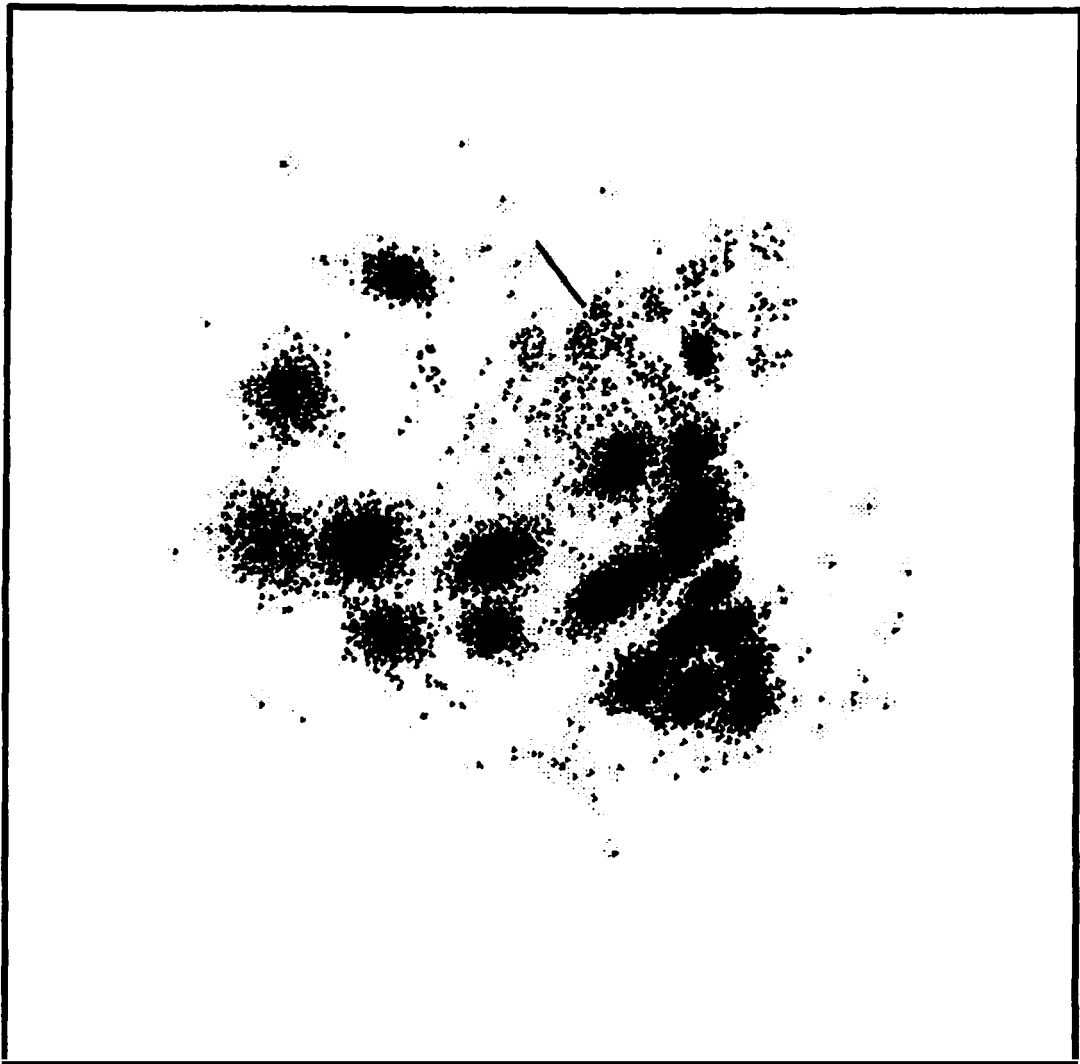


Figure 6.1. Lateral view of landmarks for all configurations prior to Procrustes fitting. Anterior is to the right and superior is to the top of the page.

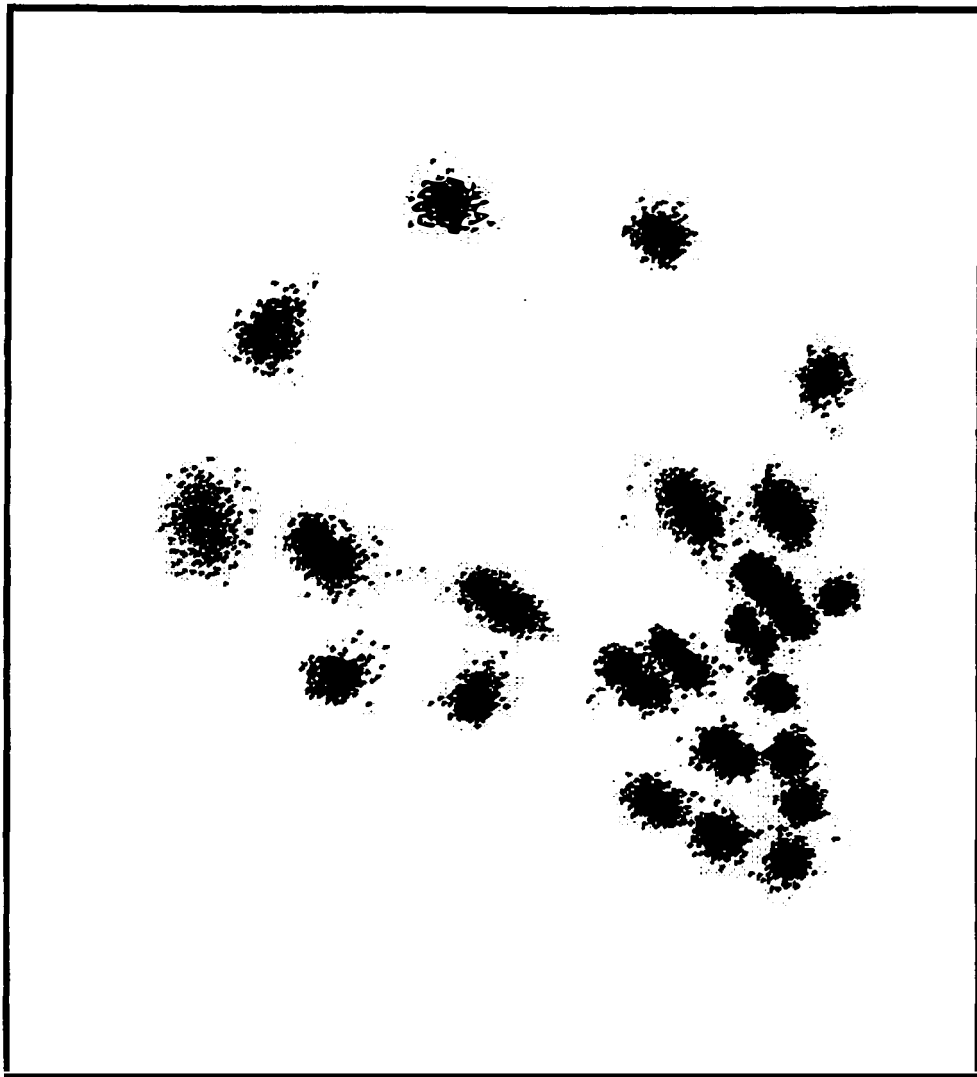


Figure 6.2. Lateral view of landmarks for all configurations after Procrustes fitting. Anterior is to the right and superior is to the top of the page.

indicates the range and degree of variation present for that landmark. The wireframe configuration shown in Figure 6.3 is a lateral view of the overall consensus configuration.

Principal Component Analysis and Investigation

Eighty non-zero principal components ($k-7$ for 29 landmarks requires dimensionality equal to 80) were extracted from the covariance matrix of the Procrustes residuals for 29 landmarks for 452 configurations. Table 6.1 provides a summary of the principal components with their corresponding eigenvalues, individual proportion of variance and cumulative proportion of variance. The first 39 principal components account for 90% of the overall variance and are used as variables for subsequent analyses. The eigenvectors for each principal component are provided in Appendix B. For the first several principal components, the eigenvectors that are contributing considerably to the principal component score tend to be associated with x and y coordinates. With regard to landmark location, the x coordinate represents superior-inferior variation and the y coordinate represents the anterior-posterior variation. This pattern of loading on the x and y coordinates justifies the use of lateral perspectives for interpreting the principal components and two-dimensional thin-plate spline analysis.

The results of an ANOVA testing for differences in principal component means across the sites shown in Table 6.2 indicates that principal components 2, 3, 5, 7, 9, 26, and 29 are all significantly different between sites at $p < 0.001$ (using the Bonnferroni adjustment for multiple univariate tests, $\alpha = .05/39 = .001$).

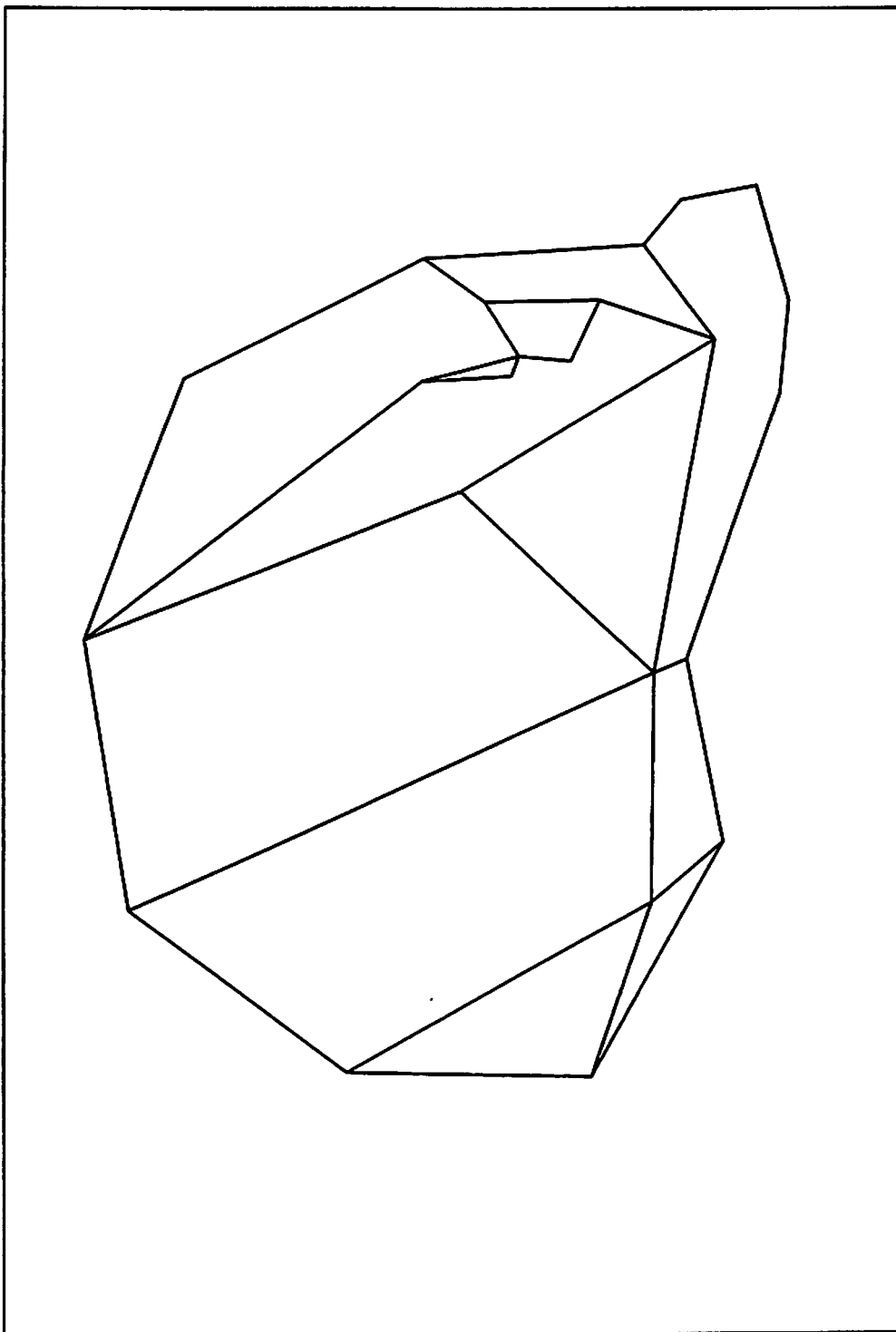


Figure 6.3. Wireframe of overall consensus configuration

Table 6.1. Eigenvalues of the covariance matrix.

PC	Eigenvalue	Difference	Proportion	Cumulative
PRIN1	0.00017	0.000026	0.089705	0.089705
PRIN2	0.000145	0.000023	0.076215	0.16592
PRIN3	0.000122	0.00001	0.064005	0.229924
PRIN4	0.000111	0.000011	0.058594	0.288519
PRIN5	0.000101	0.000013	0.052968	0.341486
PRIN6	0.000088	0.000003	0.046212	0.387698
PRIN7	0.000085	0.000004	0.044794	0.432492
PRIN8	0.000081	0.000023	0.04279	0.475282
PRIN9	0.000058	0.000007	0.030761	0.506043
PRIN10	0.000052	0.000001	0.027218	0.533261
PRIN11	0.000051	0.000004	0.026805	0.560065
PRIN12	0.000047	0.000004	0.024571	0.584636
PRIN13	0.000043	0.000003	0.0226	0.607237
PRIN14	0.00004	0.000005	0.021235	0.628472
PRIN15	0.000036	0	0.018866	0.647339
PRIN16	0.000035	0.000001	0.018642	0.665981
PRIN17	0.000034	0.000003	0.018158	0.684139
PRIN18	0.000031	0.000001	0.016317	0.700457
PRIN19	0.00003	0.000001	0.01561	0.716067
PRIN20	0.000028	0.000002	0.014852	0.730919
PRIN21	0.000027	0.000002	0.014018	0.744937
PRIN22	0.000025	0.000001	0.013055	0.757992
PRIN23	0.000023	0.000001	0.012348	0.770339
PRIN24	0.000022	0.000001	0.011775	0.782114
PRIN25	0.000021	0.000001	0.011267	0.793381
PRIN26	0.00002	0.000001	0.010699	0.80408
PRIN27	0.000019	0.000001	0.010032	0.814112
PRIN28	0.000018	0	0.009616	0.823728
PRIN29	0.000018	0.000002	0.009443	0.833171
PRIN30	0.000016	0.000001	0.008502	0.841673
PRIN31	0.000015	0	0.007715	0.849388
PRIN32	0.000014	0.000001	0.007534	0.856922
PRIN33	0.000013	0	0.007049	0.86397
PRIN34	0.000013	0.000001	0.006948	0.870919
PRIN35	0.000013	0.000001	0.006675	0.877594
PRIN36	0.000012	0.000001	0.006336	0.88393
PRIN37	0.000011	0.000001	0.006014	0.889944
PRIN38	0.000011	0	0.005729	0.895673
PRIN39	0.00001	0	0.005503	0.901176
PRIN40	0.00001	0	0.0053	0.906476
PRIN41	0.00001	0	0.005071	0.911547
PRIN42	0.000009	0	0.004888	0.916435
PRIN43	0.000009	0.000001	0.004778	0.921213
PRIN44	0.000009	0.000001	0.004476	0.925688

Table 6.1. (continued)

PC	Eigenvalue	Difference	Proportion	Cumulative
PRIN45	0.000008	0.000001	0.004195	0.929883
PRIN46	0.000007	0	0.003897	0.933781
PRIN47	0.000007	0	0.003752	0.937532
PRIN48	0.000007	0	0.003637	0.94117
PRIN49	0.000007	0.000001	0.003505	0.944674
PRIN50	0.000006	0	0.003166	0.94784
PRIN51	0.000006	0	0.003125	0.950965
PRIN52	0.000006	0	0.002992	0.953957
PRIN53	0.000005	0	0.00282	0.956777
PRIN54	0.000005	0	0.002732	0.95951
PRIN55	0.000005	0	0.002594	0.962103
PRIN56	0.000005	0	0.002536	0.964639
PRIN57	0.000005	0	0.002416	0.967056
PRIN58	0.000004	0	0.002275	0.96933
PRIN59	0.000004	0	0.002234	0.971564
PRIN60	0.000004	0	0.002196	0.97376
PRIN61	0.000004	0	0.001966	0.975726
PRIN62	0.000004	0	0.001914	0.97764
PRIN63	0.000003	0	0.001834	0.979475
PRIN64	0.000003	0	0.001821	0.981295
PRIN65	0.000003	0	0.001684	0.982979
PRIN66	0.000003	0	0.001436	0.984416
PRIN67	0.000003	0	0.001374	0.98579
PRIN68	0.000003	0	0.001365	0.987155
PRIN69	0.000002	0	0.001217	0.988371
PRIN70	0.000002	0	0.001171	0.989542
PRIN71	0.000002	0	0.00106	0.990602
PRIN72	0.000002	0	0.001025	0.991627
PRIN73	0.000002	0	0.001002	0.992629
PRIN74	0.000002	0	0.000893	0.993522
PRIN75	0.000002	0	0.000829	0.994351
PRIN76	0.000001	0	0.000777	0.995128
PRIN77	0.000001	0	0.000736	0.995864
PRIN78	0.000001	0	0.000638	0.996503
PRIN79	0.000001	0	0.000584	0.997086
PRIN80	0.000001	.	0.000523	0.997609

Total Variance = 0.0018997092

Table 6.2. Univariate test statistics from ANOVA

PC	Total STD	Pooled STD	Between STD	R-Squared	RSQ/ (1-RSQ)	F	Pr > F
PRIN1	0.0131	0.0129	0.003312	0.060716	0.0646	1.7615	0.0339
PRIN2	0.012	0.0116	0.004068	0.107834	0.1209	3.2936	0.0001
PRIN3	0.011	0.0107	0.003356	0.087391	0.0958	2.6094	0.0007
PRIN4	0.0106	0.0104	0.002686	0.061143	0.0651	1.7747	0.0321
PRIN5	0.01	0.009603	0.003516	0.1159	0.1311	3.5723	0.0001
PRIN6	0.00937	0.009278	0.002244	0.054086	0.0572	1.5581	0.0766
PRIN7	0.009225	0.008918	0.002982	0.098546	0.1093	2.9789	0.0001
PRIN8	0.009016	0.008847	0.002477	0.071212	0.0767	2.0893	0.008
PRIN9	0.007644	0.007447	0.002289	0.0846	0.0924	2.5184	0.001
PRIN10	0.007191	0.007214	0.001265	0.029173	0.03	0.8188	0.6644
PRIN11	0.007136	0.007049	0.00178	0.058677	0.0623	1.6986	0.0439
PRIN12	0.006832	0.006677	0.001973	0.078702	0.0854	2.3278	0.0026
PRIN13	0.006552	0.006505	0.001499	0.04936	0.0519	1.4149	0.1301
PRIN14	0.006351	0.006233	0.001744	0.071146	0.0766	2.0872	0.0081
PRIN15	0.005987	0.006003	0.001072	0.030223	0.0312	0.8493	0.6289
PRIN16	0.005951	0.005803	0.001763	0.082802	0.0903	2.46	0.0014
PRIN17	0.005873	0.005762	0.00162	0.071764	0.0773	2.1067	0.0074
PRIN18	0.005568	0.005547	0.001181	0.042418	0.0443	1.2071	0.2585
PRIN19	0.005446	0.005432	0.001122	0.040067	0.0417	1.1374	0.3173
PRIN20	0.005312	0.005241	0.001349	0.060844	0.0648	1.7654	0.0334
PRIN21	0.00516	0.00505	0.001466	0.076109	0.0824	2.2448	0.0039
PRIN22	0.00498	0.004903	0.001309	0.065125	0.0697	1.8983	0.0189
PRIN23	0.004843	0.004855	0.000872	0.030565	0.0315	0.8591	0.6173
PRIN24	0.004729	0.004757	0.000755	0.024023	0.0246	0.6708	0.8234
PRIN25	0.004626	0.004613	0.000966	0.041133	0.0429	1.169	0.2897
PRIN26	0.004508	0.0043	0.001625	0.122492	0.1396	3.8038	0.0001
PRIN27	0.004366	0.004387	0.000723	0.025906	0.0266	0.7247	0.7693
PRIN28	0.004274	0.00427	0.000848	0.037144	0.0386	1.0512	0.4009
PRIN29	0.004235	0.004025	0.001566	0.129015	0.1481	4.0364	0.0001
PRIN30	0.004019	0.004053	0.000573	0.019146	0.0195	0.5319	0.9303
PRIN31	0.003828	0.00382	0.000782	0.039378	0.041	1.117	0.336
PRIN32	0.003783	0.003735	0.000953	0.059831	0.0636	1.7342	0.038
PRIN33	0.003659	0.003625	0.000871	0.053406	0.0564	1.5374	0.0829
PRIN34	0.003633	0.00363	0.000719	0.036903	0.0383	1.0441	0.4082
PRIN35	0.003561	0.003515	0.0009	0.060193	0.064	1.7453	0.0363
PRIN36	0.003469	0.003435	0.000833	0.054364	0.0575	1.5666	0.0742
PRIN37	0.00338	0.003359	0.000756	0.047213	0.0496	1.3503	0.1628
PRIN38	0.003299	0.003247	0.000869	0.065408	0.07	1.9071	0.0182
PRIN39	0.003233	0.003197	0.000795	0.057071	0.0605	1.6493	0.0536

Num DF= 16 , Den DF= 436

The first principal component (PC1) accounts for almost 9% of the total variation and may represent shape related sexual dimorphism. The morphological variation reflected by PC1 is shown in Figure 6.4. The configurations depicted are the product of scaling the eigenvectors for PC1 by -0.01 (dashed line) and +0.01 (solid line) and represent hypothetical forms for negative and positive scores, respectively, on PC1. Variation at bregma, basion, and along the temporal line on the frontal (frontotemporale) corresponds to the sexually dimorphic shape variation identified by Ahlstrom (1996). Specifically, negative scores on PC1 are associated with a male morphological pattern and positive scores correspond to a female morphological pattern. Since the principal component is not significantly different across the seventeen sites (Table 6.2), it is assumed that sexual dimorphism is not patterned by group and does not need to be removed from the analysis. A bivariate plot of principal components 1 and 2 shown in Figure 6.5 illustrates the fairly equal distribution of the individuals from each site along PC1 supporting the conclusion that variation along this principal component is due to sexual dimorphism.

Morphological variation associated with principal component 2 (PC2) is shown in Figure 6.6. Variation along this component is related to forwardness of the midface region and vault length at lambda. Negative scores on PC2 correspond with a retracted middle face and a longer vault at lambda. Positive scores on PC2 are associated with midfacial forwardness and a shorter vault at lambda. Principal component 3 appears to represent variation in total facial forwardness as shown in Figure 6.7. Specifically, negative scores are associated with anteriorly positioned facial landmarks while positive

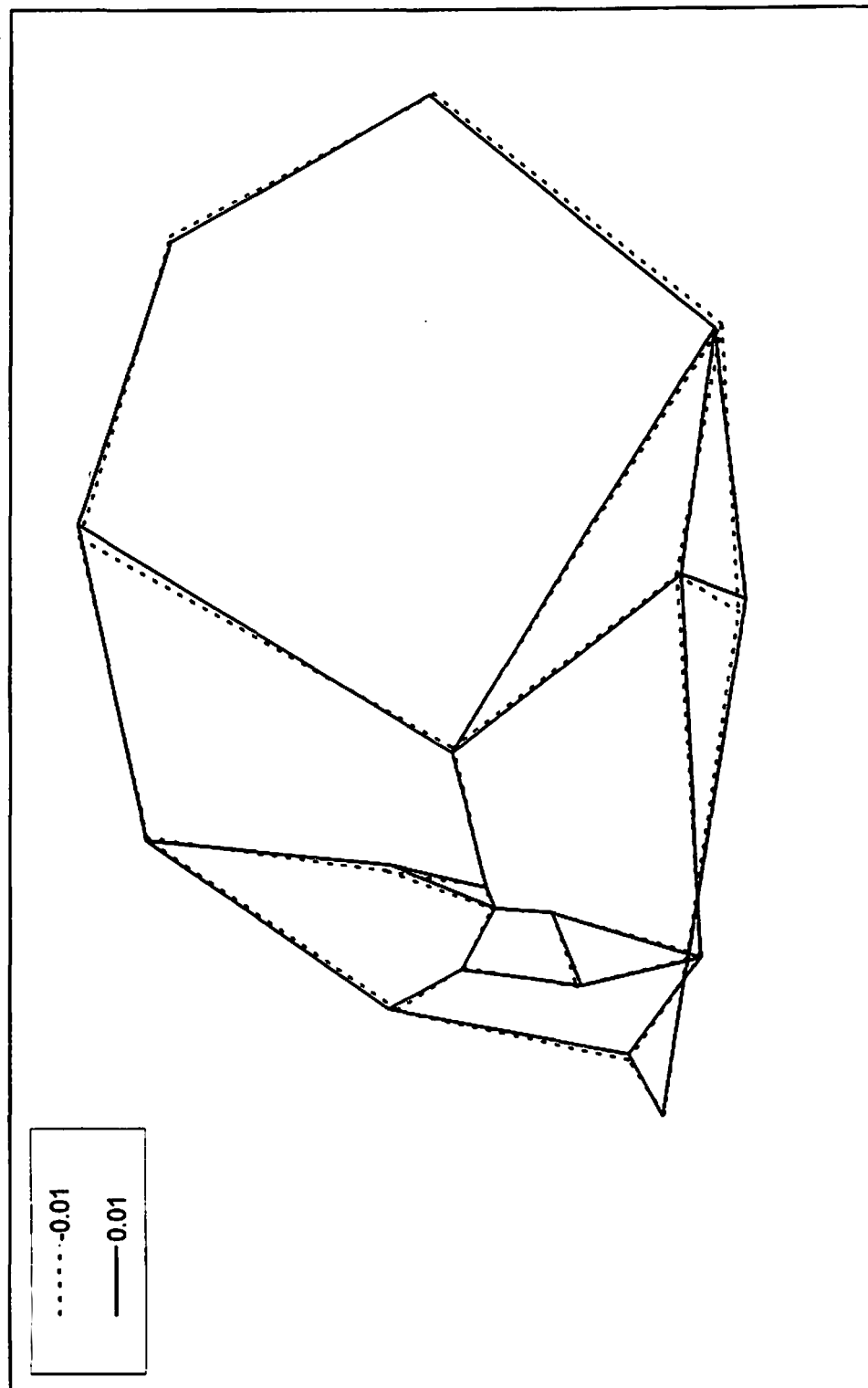


Figure 6.4. Principal Component 1

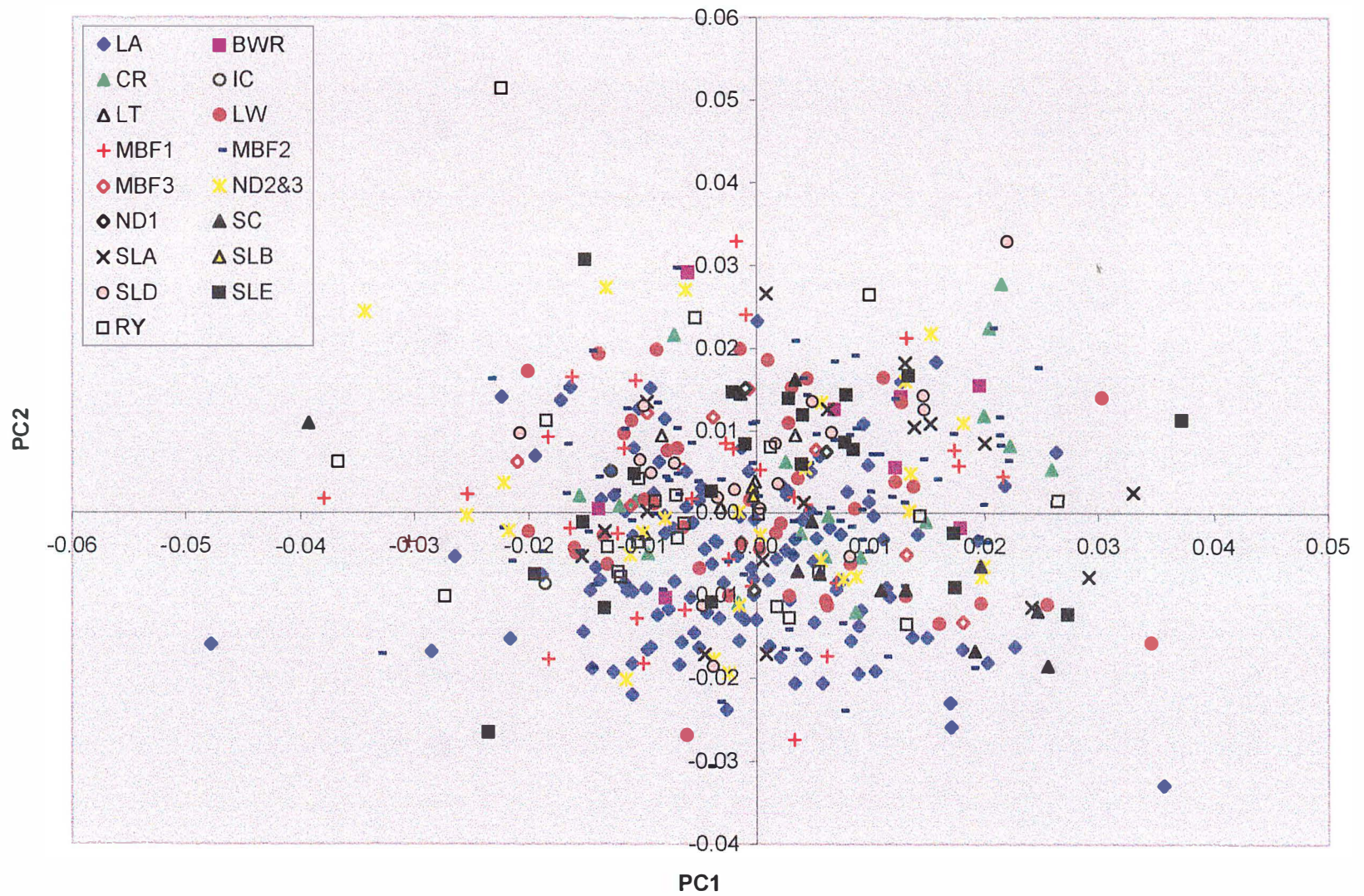


Figure 6. 5. Plot of principal components 1 and 2

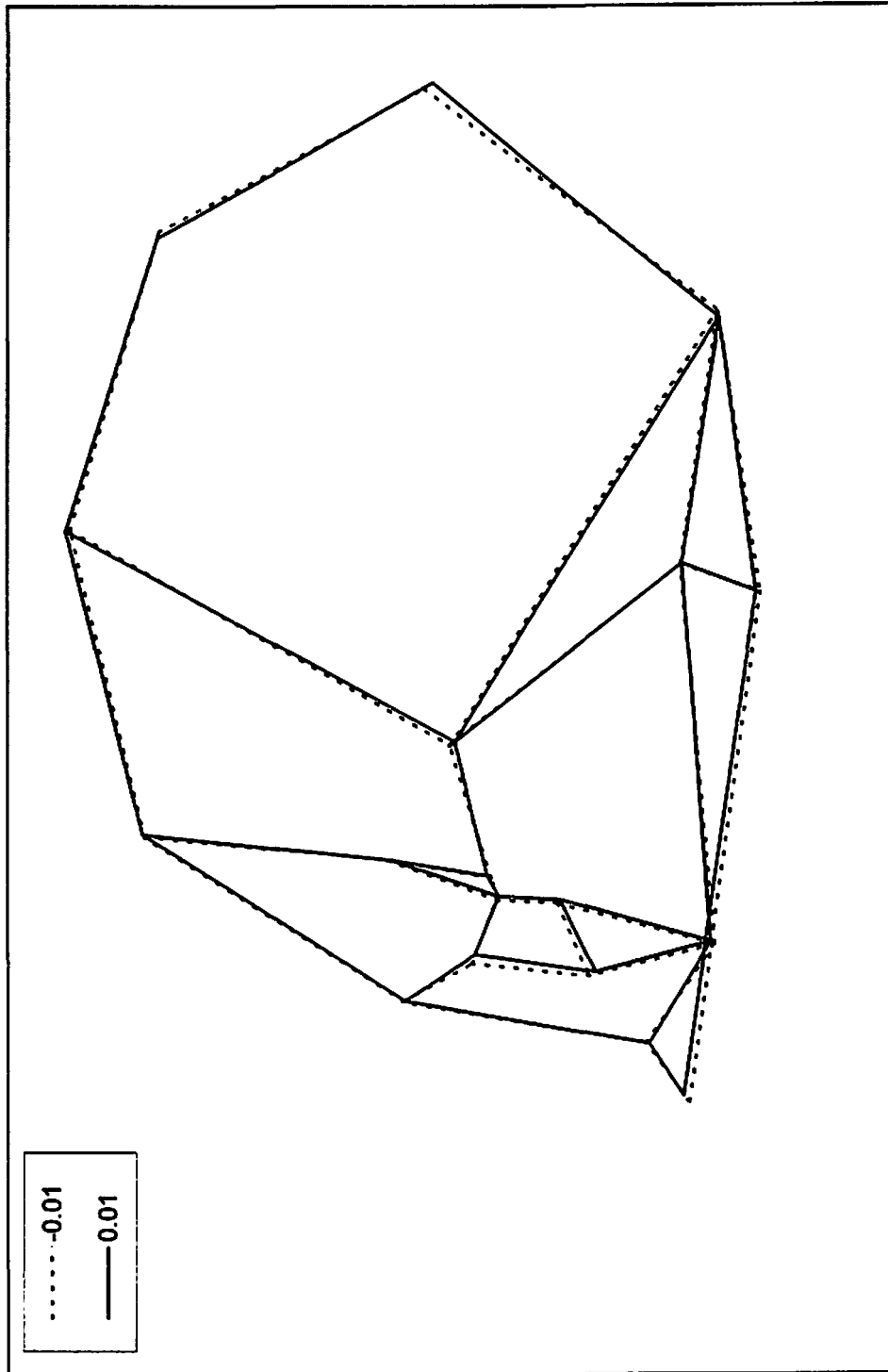


Figure 6.6. Principal Component 2

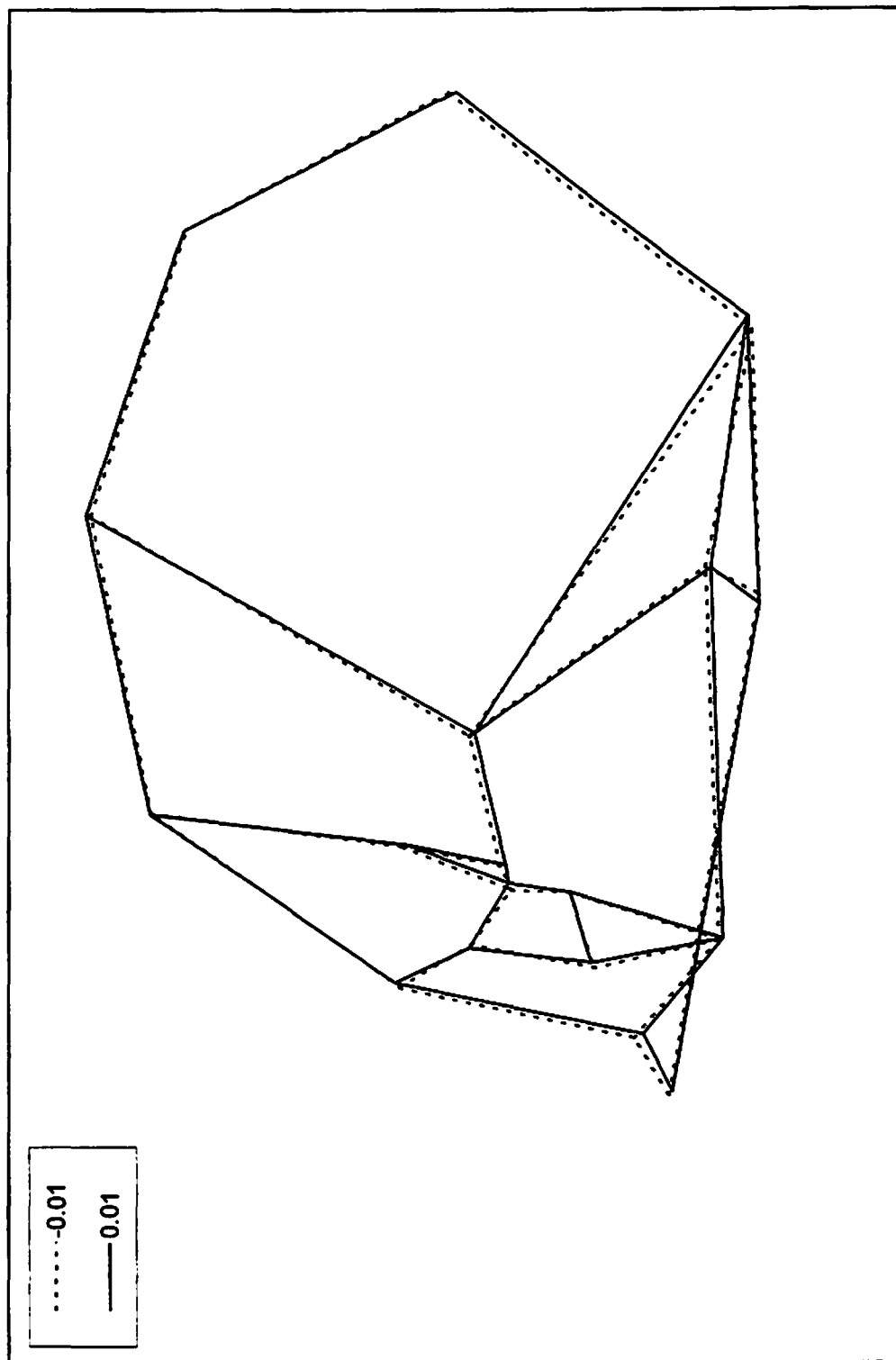


Figure 6.7. Principal Component 3

scores reflect posteriorly located facial landmarks. Principal component 4 (PC4) represents variation in arching along the frontal and vault length at lambda. As depicted in Figure 6.8, negative and positive scores on PC4 correspond with decreased arching of the frontal and a shorter vault at lambda and greater arching along the frontal and a longer vault at lambda, respectively. Principal component 5 (PC5) is related to variation in facial height and upper facial breadth. The configurations depicted in Figure 6.9 demonstrate that negative scores are associated with taller faces with wider upper faces and positive scores reflect shorter faces with narrower upper faces. Principal component 7 (PC7) reflects variation in vault proportions. As shown in Figure 6.10, negative scores on PC7 correspond with decreased superior vault height and increased cranial base height. Conversely, positive scores on PC7 are associated with increased superior vault height and decreased cranial base height. As depicted in Figure 6.11, principal component 8 (PC8) primarily represents overall vault height. Negative scores on PC8 reflect greater overall vault height and positive scores correspond with lower overall vault height.

Regression Analysis

There are no components that are unequivocally correlated with either time or longitude ($p < 0.05$). Two principal components are significantly correlated with latitude ($p < 0.05$), principal component 7 (PC7) ($p = 0.006$) and principal component 24 (PC24) ($p = 0.007$). This indicates that the sites with common latitude or north/south location are more likely to have similar scores on PC7 which in morphological terms represents

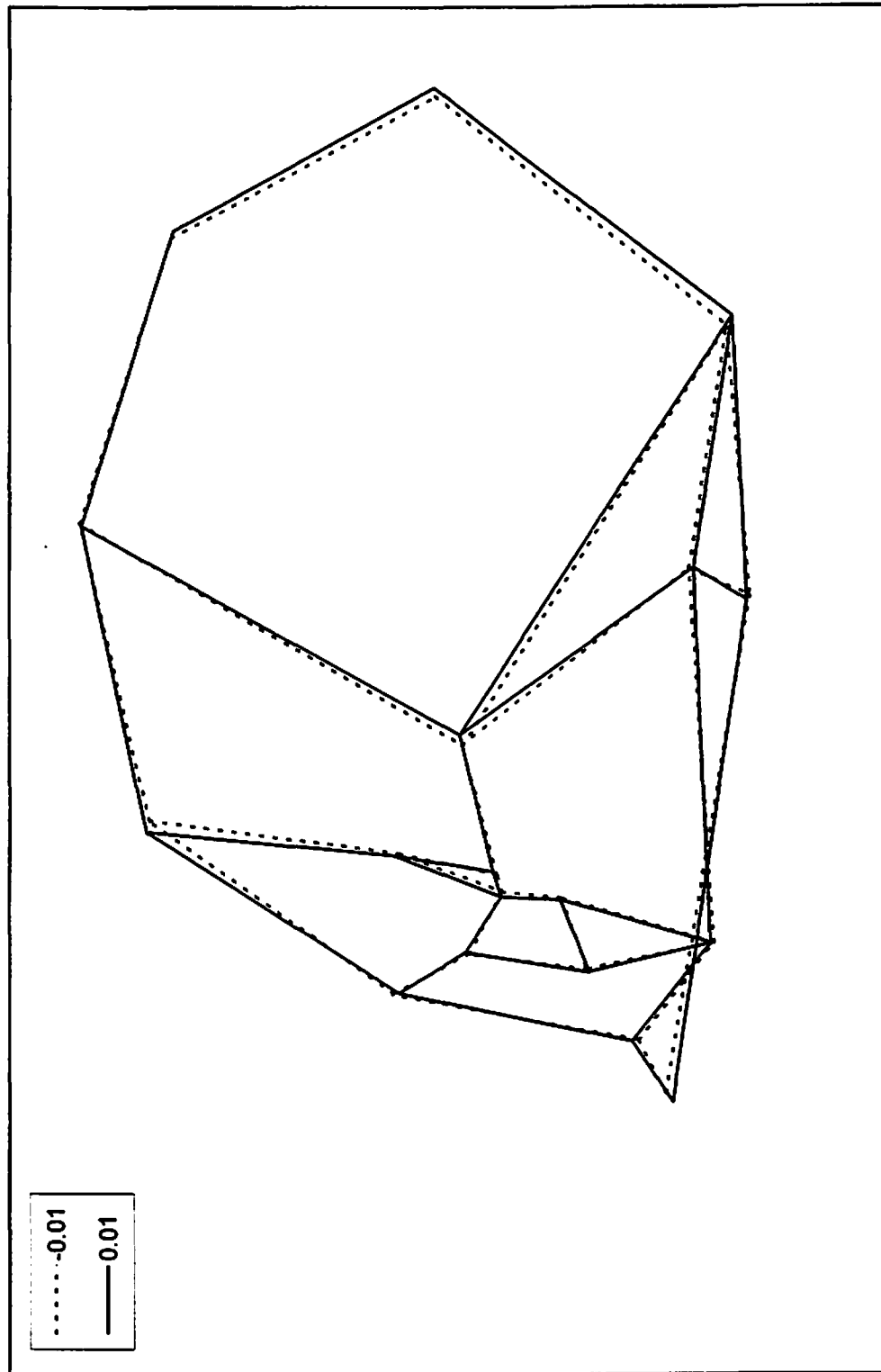


Figure 6.8. Principal Component 4

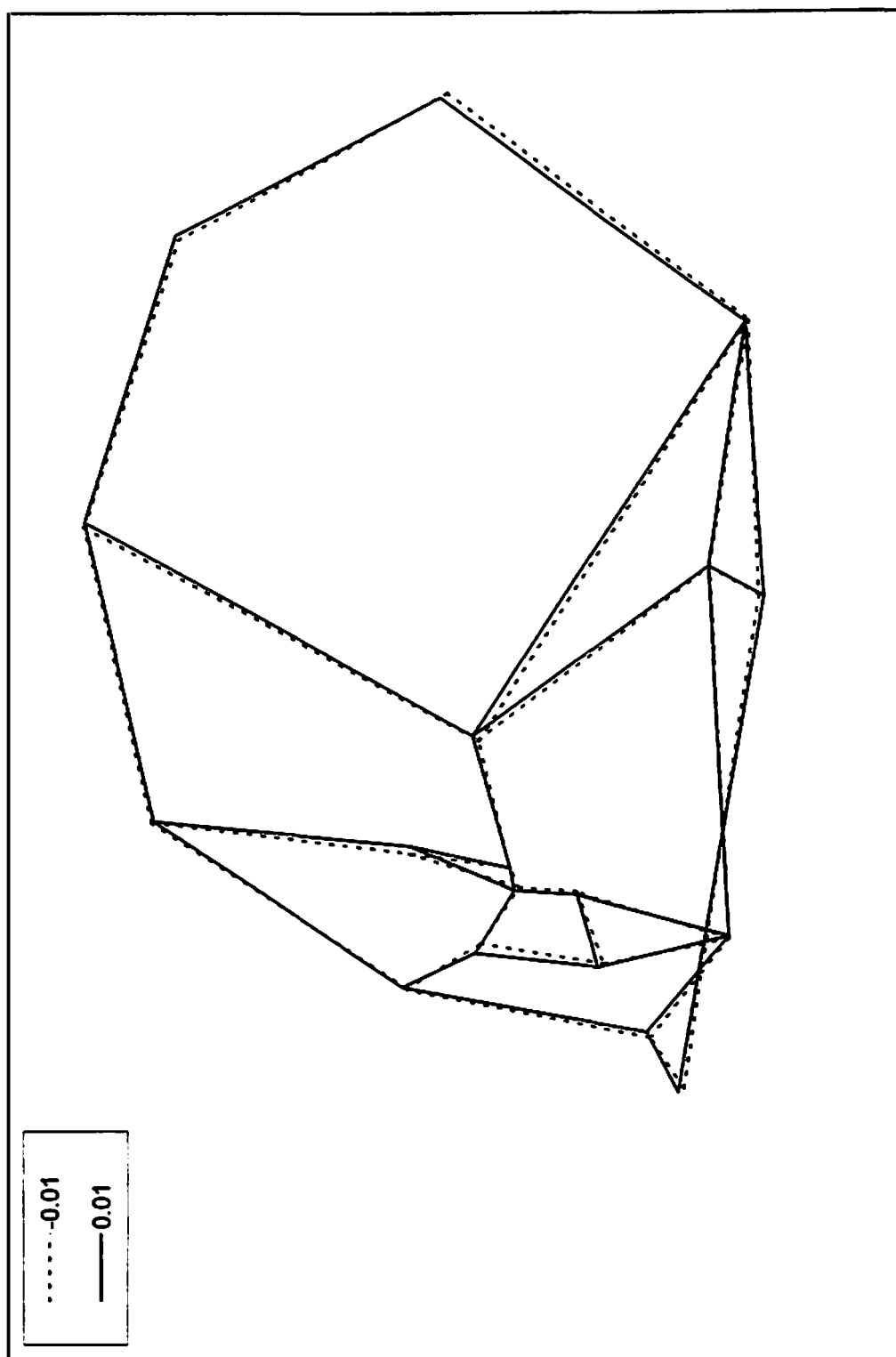


Figure 6.9. Principal Component 5

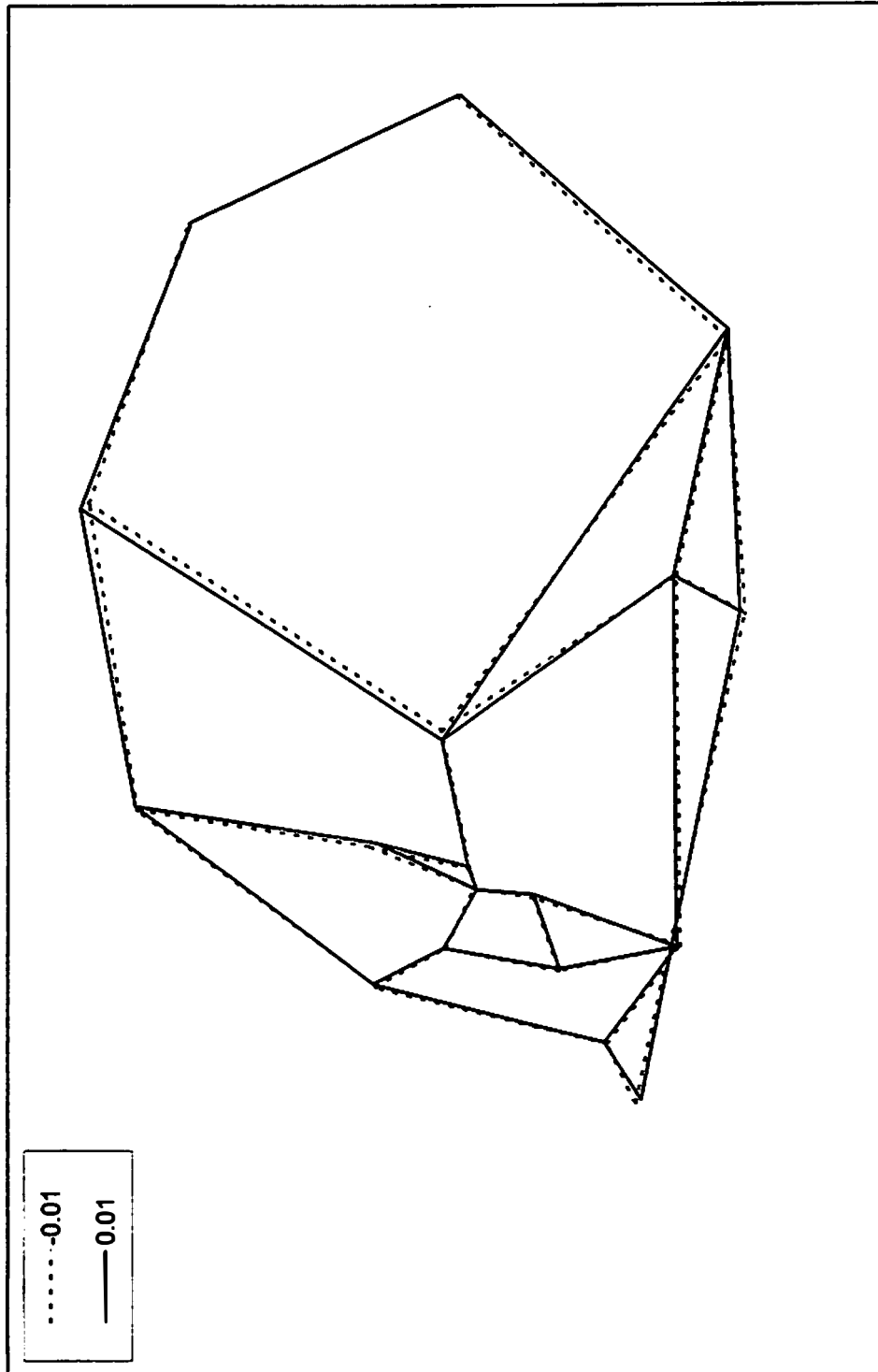


Figure 6.10. Principal Component 7

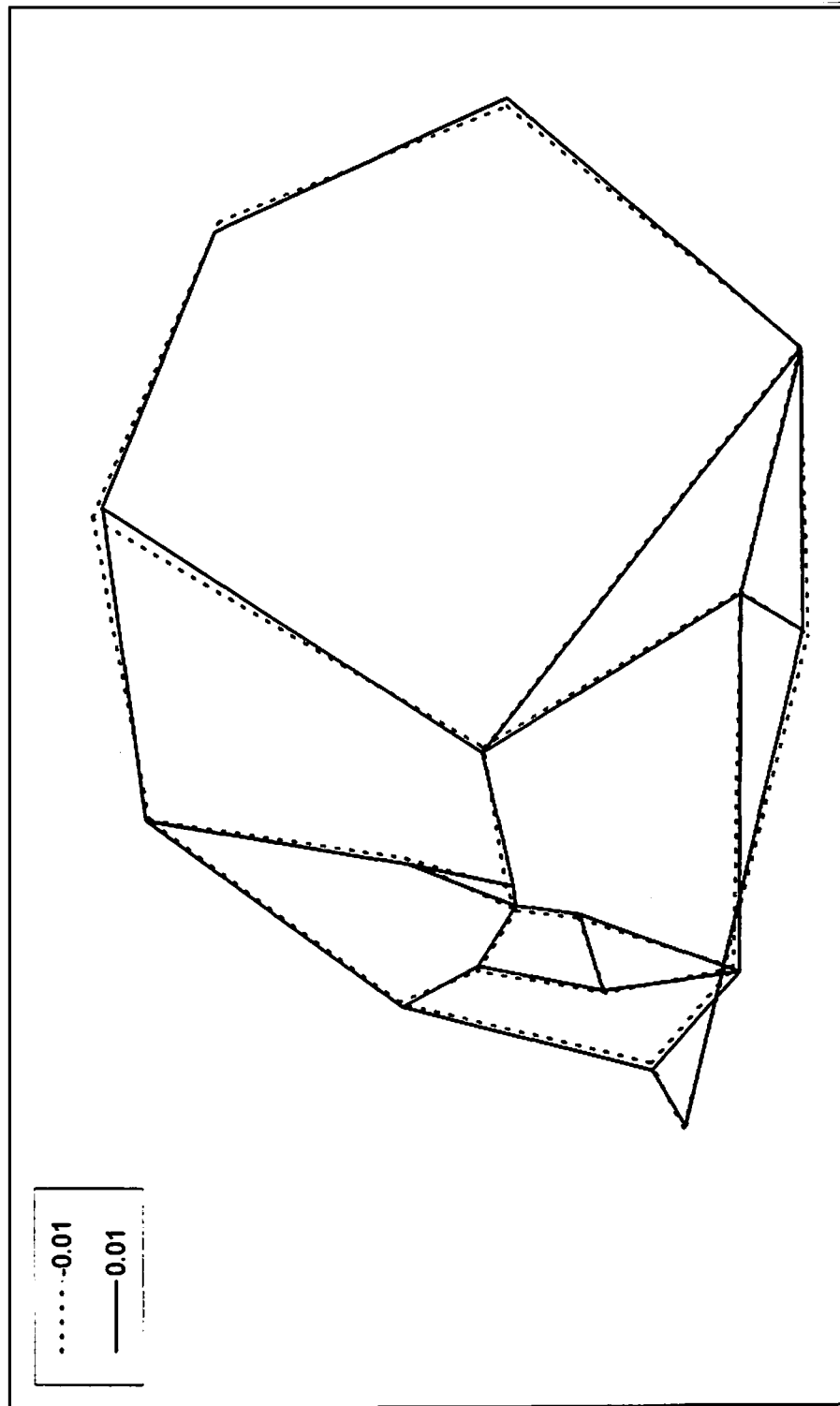


Figure 6.11. Principal Component 8

variation in the components of overall cranial vault height (superior vault height and cranial base height).

Canonical Analysis

The canonical discriminant analysis indicates that based on the overall principal component data set significant differences do exist between the individuals from the sites included in this study. Appendix C contains the summary statistics by site. Table 6.3 presents the canonical correlations for the sixteen canonical variates generated by the procedure for the seventeen sites. Table 6.4 contains the eigenvalues of the pooled covariance matrix for each of the sixteen canonical variates. The eigenvalues of the first four canonical variates cumulatively represent 65% of the total variation and, as shown in Table 6.5, significant variation among the groups exist along these variates. The first and second variates contain 22% and 17.5% of the variation, respectively, and are the most effective for separating the groups. Figure 6.12 depicts the site means along canonical variates 1 and 2. The plot of canonical means is best described as reflecting the geographic locations of the sites relative to one another. A north-south orientation is evident with the northernmost sites falling towards the positive end of the first canonical variate (CV1) and the southernmost towards the negative end of CV1. There also appears to be a left (east) bank / right (west) bank division along the second canonical variate (CV2) with most of the right bank sites scoring high on CV2 and most of the left bank sites scoring relatively low along the axis. The location of Leavenworth within the left bank range for CV2 can most likely be explained by the amalgamated nature

Table 6.3. Canonical correlations.

Canonical Variate	Adjusted Canonical Correlation	Approx Canonical Correlation	Squared Standard Error	Canonical Correlation
1	0.652874	0.5857	0.026987	0.426244
2	0.607061	0.538591	0.029702	0.368523
3	0.558135	0.479126	0.032384	0.311515
4	0.526621	0.465155	0.033992	0.27733
5	0.450246	0.350882	0.037501	0.202721
6	0.386454	.	0.040011	0.149347
7	0.37608	.	0.040383	0.141436
8	0.343728	0.250877	0.041479	0.118149
9	0.293982	.	0.042971	0.086425
10	0.274841	.	0.043483	0.075537
11	0.255463	.	0.043966	0.065261
12	0.222979	.	0.044697	0.049719
13	0.214515	.	0.044872	0.046017
14	0.188339	.	0.045368	0.035471
15	0.169759	.	0.045681	0.028818
16	0.136068	.	0.046165	0.018514

Table 6.4. Eigenvalues of the pooled covariance matrix.

Canonical Variate	Eigenvalue	Difference	Proportion	Cumulative
1	0.7429	0.1593	0.2235	0.2235
2	0.5836	0.1311	0.1756	0.3992
3	0.4525	0.0687	0.1362	0.5353
4	0.3838	0.1295	0.1155	0.6508
5	0.2543	0.0787	0.0765	0.7273
6	0.1756	0.0108	0.0528	0.7801
7	0.1647	0.0308	0.0496	0.8297
8	0.134	0.0394	0.0403	0.87
9	0.0946	0.0129	0.0285	0.8985
10	0.0817	0.0119	0.0246	0.9231
11	0.0698	0.0175	0.021	0.9441
12	0.0523	0.0041	0.0157	0.9598
13	0.0482	0.0115	0.0145	0.9743
14	0.0368	0.0071	0.0111	0.9854
15	0.0297	0.0108	0.0089	0.9943
16	0.0189	.	0.0057	1

Table 6.5. Tests of significance for canonical variates.

Canonical Variates	Likelihood Ratio	Approx F	Num DF	Den DF	Pr > F
1	0.0609068	1.9893	624	5974.16	0.0001
2	0.10615452	1.7230	570	5640.632	0.0001
3	0.16810523	1.4909	518	5302.708	0.0001
4	0.24416681	1.2930	468	4960.155	0.0001
5	0.33786761	1.0996	420	4612.732	0.0878
6	0.4237761	0.9719	374	4260.187	0.6374
7	0.49817744	0.8912	330	3902.268	0.9155
8	0.58024489	0.7949	288	3538.727	0.9945
9	0.65798503	0.7078	248	3169.33	0.9998
10	0.72023119	0.6544	210	2793.874	1.0000
11	0.77908092	0.6000	174	2412.206	1.0000
12	0.83347441	0.5434	140	2024.252	1.0000
13	0.87708246	0.5070	108	1630.059	1.0000
14	0.91938957	0.4495	78	1229.836	1.0000
15	0.95320101	0.3997	50	824	0.9999
16	0.98148556	0.3246	24	413	0.9992

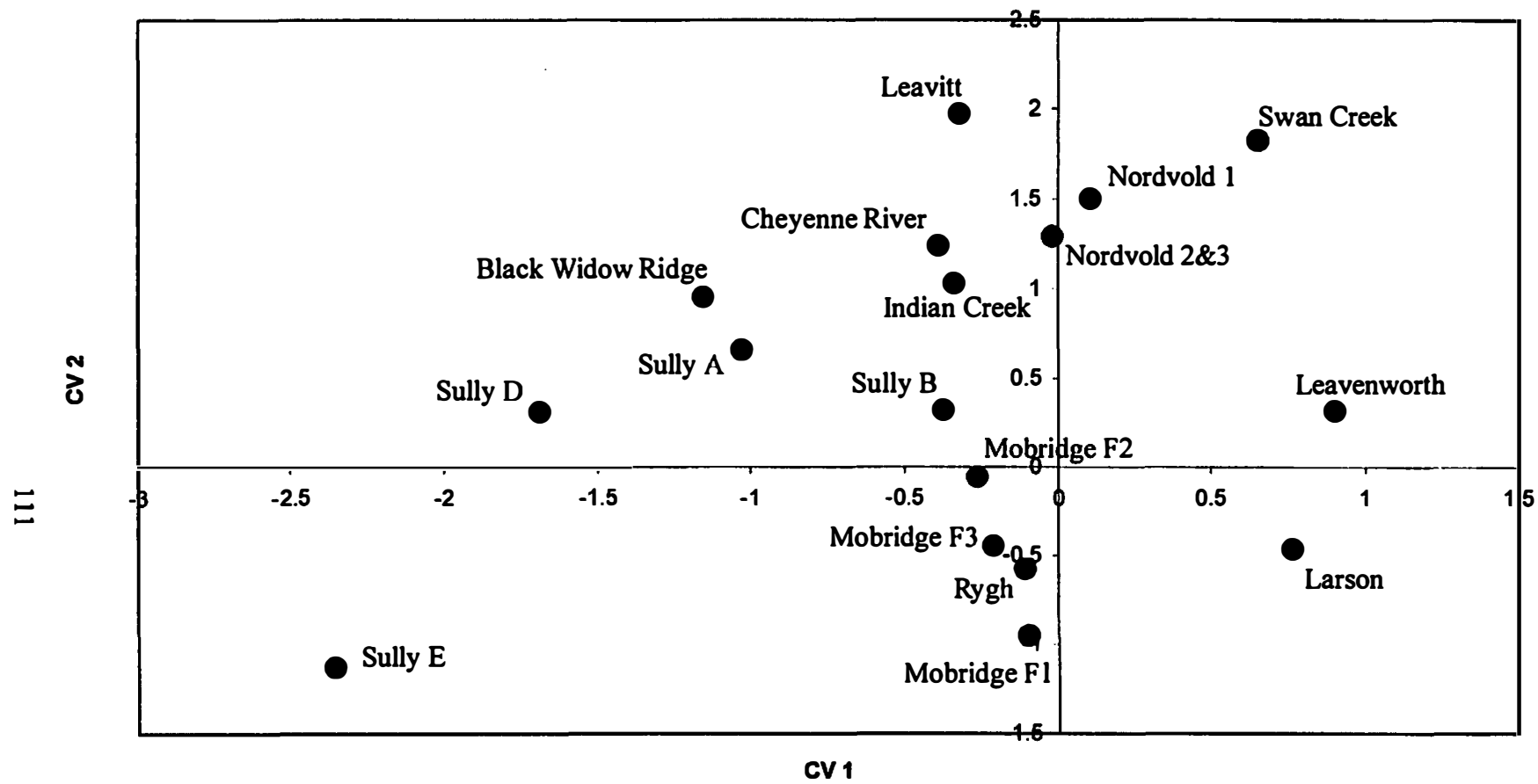


Figure 6.12. Site Means on CV 1 and 2

of the population that inhabited the site. However, the Swan Creek position is not so easily explained as it is located securely in the right bank range for CV2 quite a distance away from the other Walworth County (39WW) sites. There also appears to be a temporal orientation to the sites that runs from the lower left quadrant to upper right quadrant oblique to the canonical axes. However, there are some notable exceptions to this pattern as Sully E occupies the lower left quadrant and Nordvold 2&3 falls in the upper right quadrant placing it very close to Nordvold 1. Overall, Sully E appears to be quite distinctive as it alone occupies the far left bottom corner of the plot. A cluster of early northern sites, Mobridge features 1 and 3 and Rygh, is present and the Bad River sites (Black Widow Ridge, Cheyenne River, Indian Creek and Leavitt) occupy the same general area in the upper left quadrant of the plot. Interestingly, the Bad River “cluster” is close to both the Sully components A, B and D as well as the Nordvolds which also fall very close together. Contributions of individual principal components to the canonical variate can be used to interpret the morphological variation creating separation along the axes. From the between group canonical structure principal components loading on CV1 are PC2 (-0.725), PC7 (0.783), PC8 (0.897), PC14 (-0.727), and PC24 (0.639217). Salient loadings on CV2 are PC5 (-0.706), PC16 (0.871), and PC23 (0.758). Therefore, high scores on CV1 are associated with shorter vault length at lambda (which does not necessarily mean a shorter overall vault length), a greater height for the upper portion of the vault, a lower cranial base height and an overall decreased vault height. Conversely negative scores on CV1 correspond to a longer vault at lambda (which does not necessary indicate a longer overall vault), a decreased upper vault height, an increased cranial base

height and an overall taller vault. For CV2 positive scores reflects taller and wider faces while negative scores indicate shorter and narrower faces. The canonical plot, for the most part, summarizes the biological distances shown in Table 6.6.

The jack-knife or crossvalidation procedure did a very poor job of correctly allocating individuals by group as shown in Table 6.7. Most sites have very low rates of correct classification. Individuals from Sully E are correctly classified at a rate of 61.9% which is the best rate for any group considered. This is probably related to Sully E's distinctive morphological pattern that separates it from all other groups on CVs 1 and 2. Larson has a correct classification rate of 41.9% and Leavenworth individuals are correctly classified 34% of the time. The large number of groups included in this allocation procedure increases the probability that missclassification will occur. The exceedingly low rates of correct classification for most sites indicates that the individuals included in this study share very similar morphological patterns and that much of the variation that is present in this sample is on the individual level.

Matrix Correlation (Mantel Tests)

The biological distance matrix is compared to both geographical and temporal distance matrices. The geographical and temporal distance matrices are shown in Tables 6.8 and 6.9, respectively. The result of the matrix correspondence tests also confirms that most of the variation present among the sites is patterned in a geographic manner. Table 6.10 presents the results of the comparisons with p-values for the tests of significance.

Table 6.6. Generalized distance matrix

	BWR	CR	IC	LA	LT	LW	MBF1	MBF2	MBF3	NDI	ND2&3	RY	SC	SLA	SLB	SLD	SLE
BWR	0	12.57393	31.69326	12.68378	22.47614	16.93667	17.43513	10.92881	23.56983	16.3014	12.2019	14.19466	16.03937	11.15398	24.17166	8.60734	18.9781
CR	12.57393	0	23.01055	6.70348	10.05279	6.84551	8.89918	5.73908	11.48331	17.86393	5.00161	11.56084	6.81418	7.02277	16.17562	6.26757	13.95629
IC	31.69326	23.01055	0	23.64307	26.78748	28.20405	26.7992	22.84351	29.86027	25.73742	22.87991	21.91794	21.80128	23.58032	26.73658	26.49717	32.38208
LA	12.68378	6.70348	23.64307	0	16.16434	3.86886	4.84694	2.87752	9.50059	16.33968	5.41365	5.95525	8.30947	7.29962	15.12317	8.42296	12.83066
LT	22.47614	10.05279	26.78748	16.16434	0	14.55649	19.05313	15.32644	17.47519	22.52972	12.34487	18.38641	13.20253	14.3197	19.56213	16.5604	23.44374
LW	16.93667	6.84551	28.20405	3.86886	14.55649	0	6.60054	4.30303	9.33777	17.25943	4.76062	9.363	8.28834	8.46867	16.03754	11.75296	15.02745
MBF1	17.43513	8.89918	26.7992	4.84694	19.05313	6.60054	0	4.47752	4.47331	18.94037	8.39155	4.43842	11.6027	7.66666	17.70173	8.35589	12.27586
MBF2	10.92881	5.73908	22.84351	2.87752	15.32644	4.30303	4.47752	0	9.15252	13.61044	4.35698	5.34674	7.71876	5.05361	12.78943	5.64175	9.75198
MBF3	23.56983	11.48331	29.86027	9.50059	17.47519	9.33777	4.47331	9.15252	0	20.87843	10.92332	7.27287	13.0714	8.16285	16.22854	12.14468	16.12638
NDI	16.3014	17.86393	25.73742	16.33968	22.52972	17.25943	18.94037	13.61044	20.87843	0	13.80719	10.76075	13.67862	12.70646	29.52209	17.84571	31.47399
ND2&3	12.2019	5.00161	22.87991	5.41365	12.34487	4.76062	8.39155	4.35698	10.92332	13.80719	0	9.54126	4.83051	5.31556	16.9809	7.38332	14.23639
RY	14.19466	11.56084	21.91794	5.95525	18.38641	9.363	4.43842	5.34674	7.27287	10.76075	9.54126	0	11.20733	7.02643	17.73869	9.1411	15.96017
SC	16.03937	6.81418	21.80128	8.30947	13.20253	8.28834	11.6027	7.71876	13.0714	13.67862	4.83051	11.20733	0	8.57303	15.36217	13.27534	23.23687
SLA	11.15398	7.02277	23.58032	7.29962	14.3197	8.46867	7.66666	5.05361	8.16285	12.70646	5.31556	7.02643	8.57303	0	15.69017	5.41729	11.17642
SLB	24.17166	16.17562	26.73658	15.12317	19.56213	16.03754	17.70173	12.78943	16.22854	29.52209	16.9809	17.73869	15.36217	15.69017	0	19.58698	19.64481
SLD	8.60734	6.26757	26.49717	8.42296	16.5604	11.75296	8.35589	5.64175	12.14468	17.84571	7.38332	9.1411	13.27534	5.41729	19.58698	0	9.43861
SLE	18.9781	13.95629	32.38208	12.83066	23.44374	15.02745	12.27586	9.75198	16.12638	31.47399	14.23639	15.96017	23.23687	11.17642	19.64481	9.43861	0

Table 6.7. Results of cross validation based allocation procedure. The top number represents the number of individuals allocated to the group and the bottom number is the percentage of total sample.

From	To																
	BWR	CR	IC	LA	LT	LW	MBF1	MBF2	MBF3	ND1	ND2&3	RY	SC	SLA	SLB	SLD	SLE
BWR	2 25	1 12.5	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1 12.5	0 0	0 0	2 25	0 0	1 12.5	1 12.5
CR	2 11.11	4 22.22	0 0	1 5.56	2 11.11	0 0	0 0	1 5.56	0 0	0 0	4 22.22	0 0	0 0	1 5.56	1 5.56	1 5.56	1 5.56
IC	0 0	1 50	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1 50	0 0	0 0	0 0	0 0	0 0
LA	5 3.88	5 3.88	2 1.55	54 41.86	0 0	16 12.4	8 6.2	6 4.65	2 1.55	1 0.78	4 3.1	7 5.43	6 4.65	4 3.1	3 2.33	5 3.88	1 0.78
LT	0 0	2 40	0 0	0 0	1 20	0 0	0 0	0 0	0 0	0 0	1 20	0 0	0 0	1 20	0 0	0 0	0 0
LW	0 0	0 0	0 0	8 18.18	2 4.55	15 34.09	4 9.09	4 9.09	1 2.27	1 2.27	3 6.82	0 0	4 9.09	0 0	2 4.55	0 0	0 0
MBF1	0 0	1 3.23	0 0	4 12.9	0 0	4 12.9	6 19.35	1 3.23	5 16.13	0 0	0 0	5 16.13	0 0	1 3.23	0 0	2 6.45	2 6.45
MBF2	3 3.53	4 4.71	0 0	15 17.65	1 1.18	4 4.71	7 8.24	18 21.18	2 2.35	2 2.35	4 4.71	4 4.71	4 4.71	3 3.53	2 2.35	8 9.41	4 4.71
MBF3	0 0	0 0	0 0	0 0	0 0	1 12.5	4 50	0 0	0 0	0 0	1 12.5	1 12.5	0 0	1 12.5	0 0	0 0	0 0
ND1	0 0	0 0	0 0	1 33.33	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1 33.33	1 33.33	0 0	0 0	0 0	0 0

Table 6.7. (continued)

From	To																
	BWR	CR	IC	LA	LT	LW	MBF1	MBF2	MBF3	ND1	ND2&3	RY	SC	SLA	SLB	SLD	SLE
ND2&3	0	3	0	0	1	3	1	2	1	1	4	2	5	1	0	2	1
	0	11.11	0	0	3.7	11.11	3.7	7.41	3.7	3.7	14.81	7.41	18.52	3.7	0	7.41	3.7
RY	3	0	0	2	0	0	4	1	3	2	0	4	0	2	1	1	0
	13.04	0	0	8.7	0	0	17.39	4.35	13.04	8.7	0	17.39	0	8.7	4.35	4.35	0
SC	0	2	0	0	0	0	1	0	0	0	3	2	2	1	1	0	0
	0	16.67	0	0	0	0	8.33	0	0	0	25	16.67	16.67	8.33	8.33	0	0
SLA	0	1	0	0	1	1	0	1	1	1	1	1	2	1	0	4	2
	0	5.88	0	0	5.88	5.88	0	5.88	5.88	5.88	5.88	5.88	11.76	5.88	0	23.53	11.76
SLB	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0
	0	0	0	50	0	0	0	0	50	0	0	0	0	0	0	0	0
SLD	3	3	0	0	0	0	0	0	0	0	2	2	0	3	0	1	4
	16.67	16.67	0	0	0	0	0	0	0	0	11.11	11.11	0	16.67	0	5.56	22.22
SLE	1	0	0	1	0	0	1	1	0	0	1	0	0	1	0	2	13
	4.76	0	0	4.76	0	0	4.76	4.76	0	0	4.76	0	0	4.76	0	9.52	61.9

Table 6.8. Geographic distance matrix.

	LA	BWR	CR	IC	LT	LW	MBF1	MBF2	MBF3	ND2&3	ND1	SC	SLA	SLB	SLD	SLE	RY
LA	0	55.8	47.5	66	64.8	0	0	0	0	0	0	0	56.3	56.3	56.3	56.3	0
BWR	55.8	0	0	0	0	65	58	58	58	61	61	44.6	0	0	0	0	63.1
CR	47.5	0	0	25.1	23.8	56.7	49.4	49.4	49.4	52.4	52.4	37.7	0	0	0	0	54.7
IC	66	0	25.1	0	0	75	68.5	68.5	68.5	71.5	71.5	53.5	0	0	0	0	73.2
LT	64.8	0	23.8	0	0	73.8	67.3	67.3	67.3	70.2	70.2	52.4	0	0	0	0	72
LW	0	65	56.7	75	73.8	0	0	0	0	0	0	21.8	65.5	65.5	65.5	65.5	0
MBF1	0	58	49.4	68.5	67.3	0	0	0	0	0	0	16.5	58.5	58.5	58.5	58.5	0
MBF2	0	58	49.4	68.5	67.3	0	0	0	0	0	0	16.5	58.5	58.5	58.5	58.5	0
MBF3	0	58	49.4	68.5	67.3	0	0	0	0	0	0	16.5	58.5	58.5	58.5	58.5	0
ND2&3	0	61	52.4	71.5	70.2	0	0	0	0	0	0	19.1	61.5	61.5	61.5	61.5	0
ND1	0	61	52.4	71.5	70.2	0	0	0	0	0	0	19.1	61.5	61.5	61.5	61.5	0
SC	0	44.6	37.7	53.5	52.4	21.8	16.5	16.5	16.5	19.1	19.1	0	44.9	44.9	44.9	44.9	20.2
SLA	56.3	0	0	0	0	65.5	58.5	58.5	58.5	61.5	61.5	44.9	0	0	0	0	63.6
SLB	56.3	0	0	0	0	65.5	58.5	58.5	58.5	61.5	61.5	44.9	0	0	0	0	63.6
SLD	56.3	0	0	0	0	65.5	58.5	58.5	58.5	61.5	61.5	44.9	0	0	0	0	63.6
SLE	56.3	0	0	0	0	65.5	58.5	58.5	58.5	61.5	61.5	44.9	0	0	0	0	63.6
RY	0	63.1	54.7	73.2	72	0	0	0	0	0	0	20.2	63.6	63.6	63.6	63.6	0

Table 6.9. Temporal distance matrix

	LA	BWR	CR	IC	LT	LW	MBF1	MBF2	MBF3	ND2&3	ND1	SC	SLA	SLB	SLD	SLE	RY
LA	0	1.5	61.5	1.5	60	111	81	18.5	81	93.5	21.5	6	43.5	0	43.5	18.5	81
BWR	1.5	0	60	0	58.5	109.5	82.5	20	82.5	95	20	7.5	45	1.5	45	20	82.5
CR	61.5	60	0	60	1.5	49.5	142.5	80	142.5	155	40	67.5	105	61.5	105	80	142.5
IC	1.5	0	60	0	58.5	109.5	82.5	20	82.5	95	20	7.5	45	1.5	45	20	82.5
LT	60	58.5	1.5	58.5	0	51	141	78.5	141	153.5	38.5	60	103.5	60	103.5	78.5	141
LW	111	109.5	49.5	109.5	51	0	192	129.5	192	204.5	89.5	117	154.5	111	154.5	129.5	192
MBF1	81	82.5	142.5	82.5	141	192	0	62.5	0	12.5	102.5	75	37.5	81	37.5	62.5	0
MBF2	18.5	20	80	20	78.5	129.5	62.5	0	62.5	75	40	12.5	25	18.5	25	0	62.5
MBF3	81	82.5	142.5	82.5	141	192	0	62.5	0	12.5	102.5	75	37.5	81	37.5	62.5	0
ND2&3	93.5	95	155	95	153.5	204.5	12.5	75	12.5	0	115	87.5	50	93.5	50	75	12.5
ND1	21.5	20	40	20	38.5	89.5	102.5	40	102.5	115	0	27.5	65	21.5	65	40	102.5
SC	6	7.5	67.5	7.5	66	117	75	12.5	75	87.5	27.5	0	37.5	6	37.5	12.5	75
SLA	43.5	45	105	45	103.5	154.5	37.5	25	37.5	50	65	37.5	0	43.5	0	25	37.5
SLB	0	1.5	61.5	1.5	60	111	81	18.5	81	93.5	21.5	6	43.5	0	43.5	18.5	81
SLD	43.5	45	105	45	103.5	154.5	37.5	25	37.5	50	65	37.5	0	43.5	0	25	37.5
SLE	18.5	20	80	20	78.5	129.5	62.5	0	62.5	75	40	12.5	25	18.5	25	0	62.5
RY	81	82.5	142.5	82.5	141	192	0	62.5	0	12.5	102.5	75	37.5	81	37.5	62.5	0

Table 6.10. Mantel matrix correlation results

Biological Compared to	Controlling for	Correlation	Random > Observed	p-value
Geographic		0.18557	1	0.0039
Temporal		-0.14150	398	0.7964
Geographic	Temporal	0.18544	2	0.0059
Temporal	Geographic	-0.17200	412	0.8243

The correlation between the biological and geographical distance matrix is 0.186 ($p = 0.0039$) and when the temporal distance matrix is added and held constant the correlation is 0.185 ($p = 0.0059$). The correspondence between the biological and temporal distance matrices is -0.142 ($p = 0.7964$) and when the geographic matrix is added and held constant the correlation is -0.172 ($p = 0.8243$). Konigsberg (1990) demonstrated that if subpopulations separated by time and geography are practicing a pattern of fixed migration, then a positive correlation between the biological and geographic distance matrices with the temporal matrix held constant is expected and a negative correlation between the biological and temporal distance matrices with the geographic distance matrix held constant is expected. The positive correlation between the biological and geographic distance matrices conforms to a pattern of isolation by distance. The negative temporal correlation is due to the homogenizing effect of gene flow through time. The positive geographic correlation indicates that when the geographical distance between sites is low or high, the corresponding biological distance is proportionately similar. While the temporal correlation is not statistically significant, it does indicate that, to some degree, as temporal distance increases, biological distance decreases most likely due to gene flow among the sites through time.

Thin-Plate Splines

Based on the above analyses, comparing differences in overall morphological patterns across geographic space seems appropriate. A better understanding of the nature and magnitude of the morphological differences that are represented by the biological

distances among the groups will illuminate the patterns of gene flow that occurred within this tribe through time. Employing the GLS procedure in GRF-ND, mean configurations were derived for sets of sites that appear closely related based on the previous analyses and share a common geographical location or temporal period. The sites, Black Widow Ridge, Leavitt, Indian Creek, and Cheyenne River, were consolidated into a Bad River group. The two early Sully components, Sully A and D, were combined to form the Early South group. The early components from Mobridge, F1 and F3, were merged with the Rygh site to create the Early North group. The mean configurations from these groups and individuals are compared to mean configurations from other groups and individual sites via Procrustes fitting and wireframe plots. When interpreting the overlay plots of consensus configurations, remember that the configurations were fitted so as to minimize the sum of squares differences across landmarks.

As revealed by the matrix correlation tests, groups that are geographically close together tend to have lower biological distances and vice versa. So we need to consider the subtle differences among sites with common geographical location, such as the Mobridge components, and the less subtle differences present in sites that appear distinct from their nearest geographical neighbors, such as Sully E and Swan Creek. Morphological variation that characterizes the separation across greater geographic space taking into account time, such as the variation present between the Early South sites (Sully A and D) and the early northern sites (Mobridge F1 and F3 and Rygh), and the similarities present between geographically close sites that are thought to represent cultural variants, such as Sully A and D and Bad River sites, will also be evaluated.

The thin-plate spline plot shown in Figure 6.13 depicts the deformation needed to take the space of the mean configuration for a combined Mobridge F1 and F3 sample and put it into the space occupied by the mean configuration of Mobridge F2. If no deformation or bending was necessary to complete the transformation, the grid would remain unaltered with each unit of the grid maintaining a square shape. Based on the stretching and compression depicted in the plot, there are differences between the two mean configurations which are taken into account by the statistical transformation. The process of deforming the Mobridge F2/F3 mean onto the Mobridge F3 mean results in anteriorly oriented stretching at the asterions and the zygomatic roots (auriculares) as well as slight anterior stretching is indicated at midfrontal and the landmarks of the lower maxilla. There is slight stretching across the vault with midparietal being pulled superiorly and posterior occipital extended postero-inferiorly. An overlay plot of the two mean configurations is shown in Figure 6.14 and the deformation necessitated by the thin-plate spline transformation is observed as differences between the two means. The vault of the Mobridge F2 consensus configuration is indeed slightly higher across the superior sagittal border and more anterior along the anterior frontal profile. Overall, the later Mobridge F2 consensus configuration exhibits a slightly higher and longer vault than the Mobridge F1/F3 mean.

Swan Creek does not cluster with other sites from the same geographic area and based on the biological distance matrix, Swan Creek is closest to Nordvold 2&3. The thin-plate spline plot shown in Figure 6.15 depicts the deformation needed to map the landmarks of the Swan Creek mean configuration onto the mean configuration from the

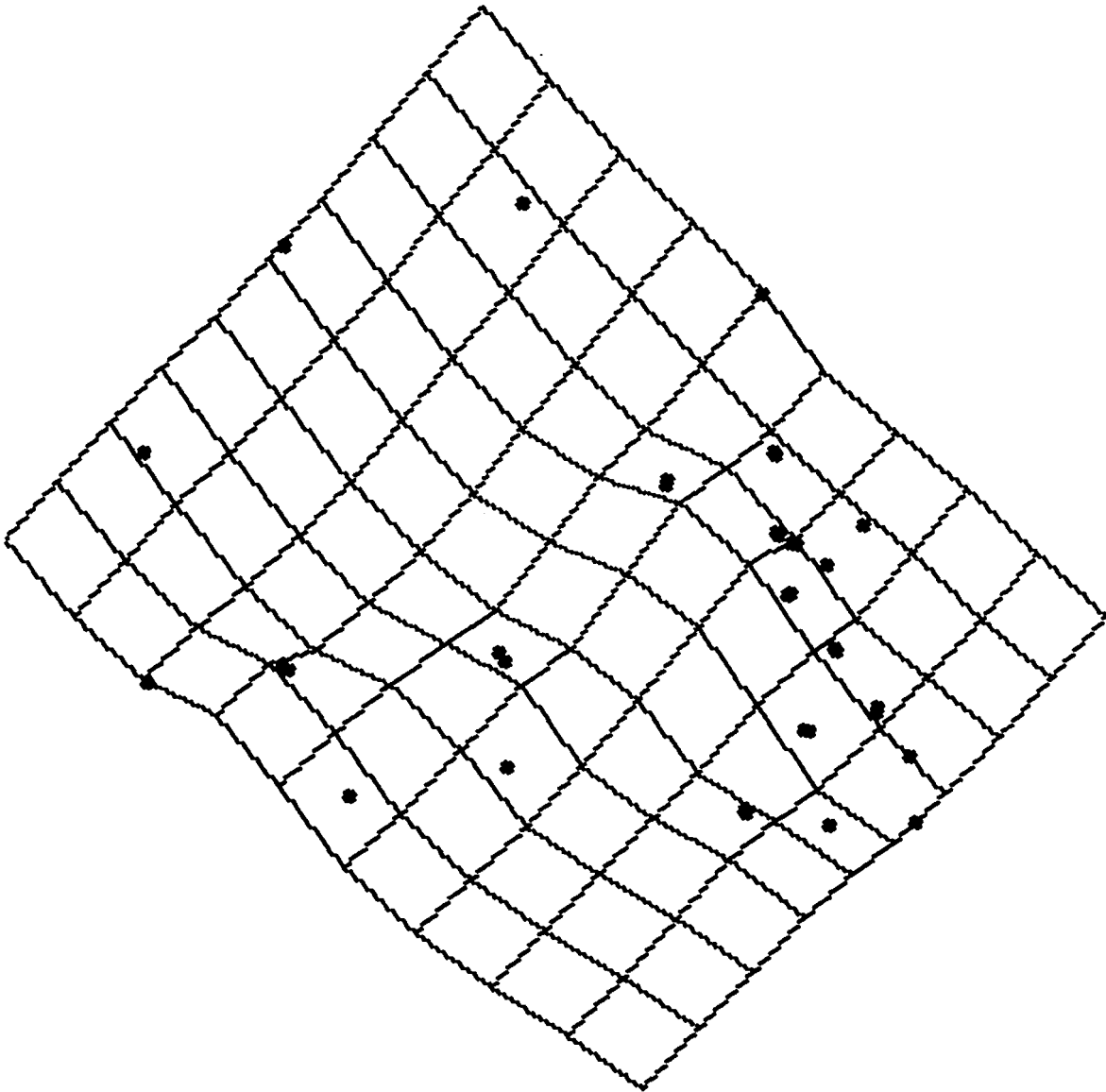


Figure 6.13. Thin-plate spline plot of mean configurations from Mobridge F1/F3 and Mobridge F2. Anterior is to the right and superior to the top of the page.

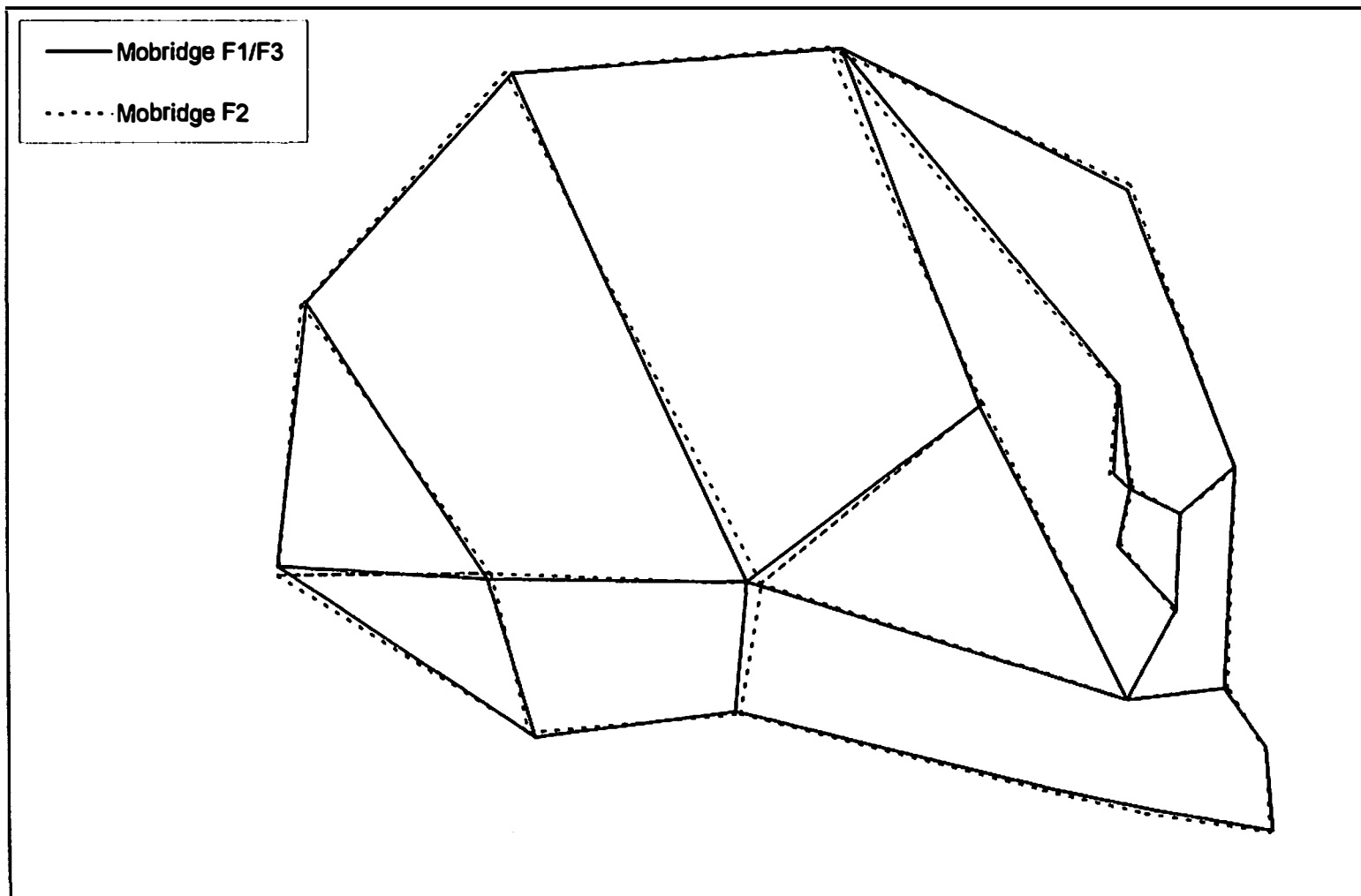


Figure 6.14. Consensus configurations for Mobridge F1/F3 and Mobridge F2.

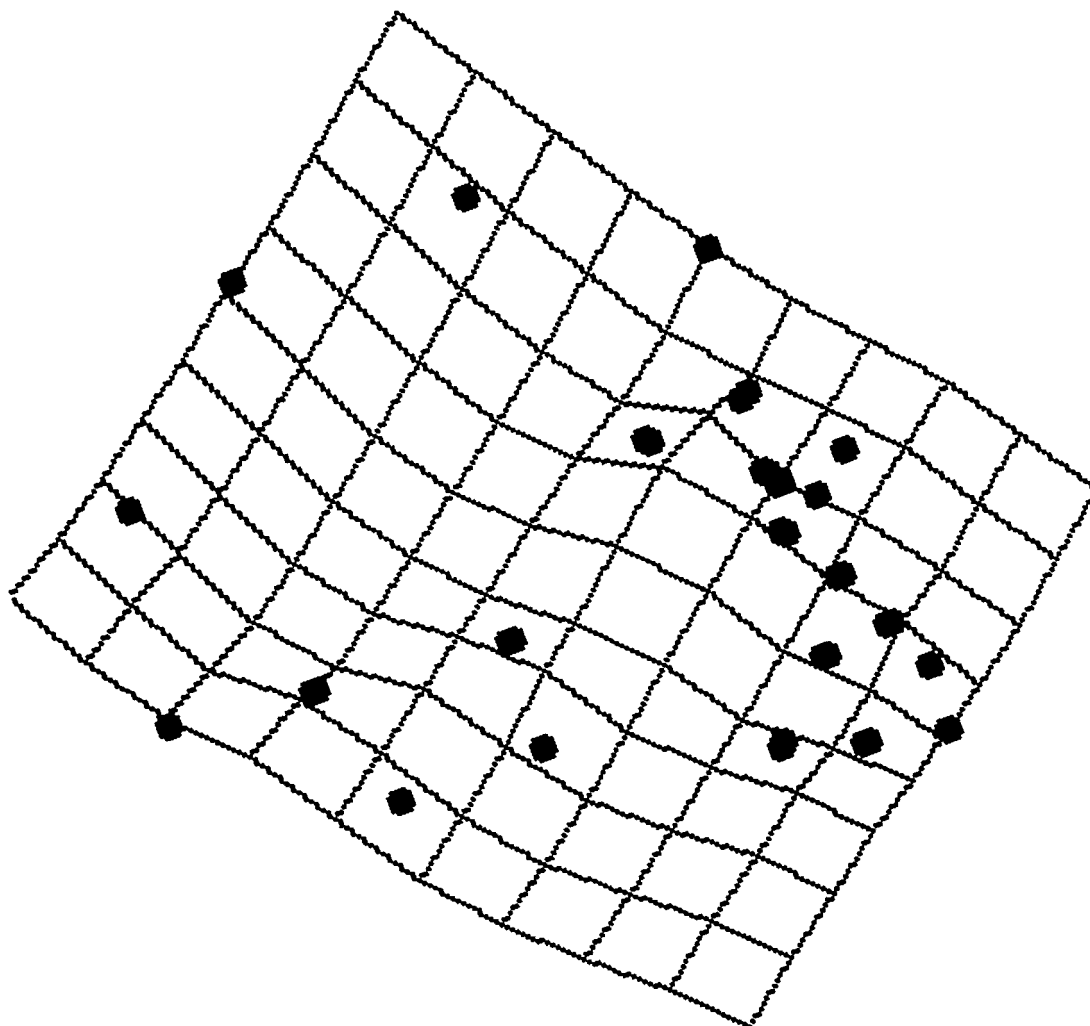


Figure 6.15. Thin-plate spline plot of mean configurations from Swan Creek and Larson. Anterior is to the right and superior is to the top of the page.

Larson sample. Due to similarity in geography and cultural attribution, it would be expected that these sites exhibit common morphological patterns. Compression is evident at midfrontal and bregma while posterior occipital is stretched superior-posteriorly. Stretching is also present in the lower face and along the cranial base. Compression is apparent between the frontotemporales and pterions. The plot depicting both mean configurations is shown in Figure 6.16 and it illustrates many of the differences indicated in the thin-plate spline plot. The Swan Creek configuration exhibits a shorter vault and a more posteriorly located temporal line as indicated by the position of frontotemporale. The inferiorly positioned basion and opisthion prevent any real differences in overall vault height (as measured from basion to bregma). The slight differences in the location of some facial landmarks is reflected in the deformation present in the transformation grid. Overall differences in the configurations are related to vault length and facial architecture.

The location of Sully E relative to the other sites on the canonical plot indicates that is distinct, in some manner, from the other sites considered. A comparison of the mean configuration from Sully E with a mean configuration for the merged sites of Sully A and D may help interpret the morphological differences that are responsible for the distinctive nature of the sample. The thin-plate spline plot with Sully E serving as the reference and the mean configuration for Sully A and D as the target is shown in Figure 6.17. Slight anterior stretching is evident in the lower face and at midfrontal. Both the zygomatic roots (auriculares) and postoccipital exhibit some posterior stretching while the grid is pulled superiorly along the cranial base. Other vault landmark locations seem

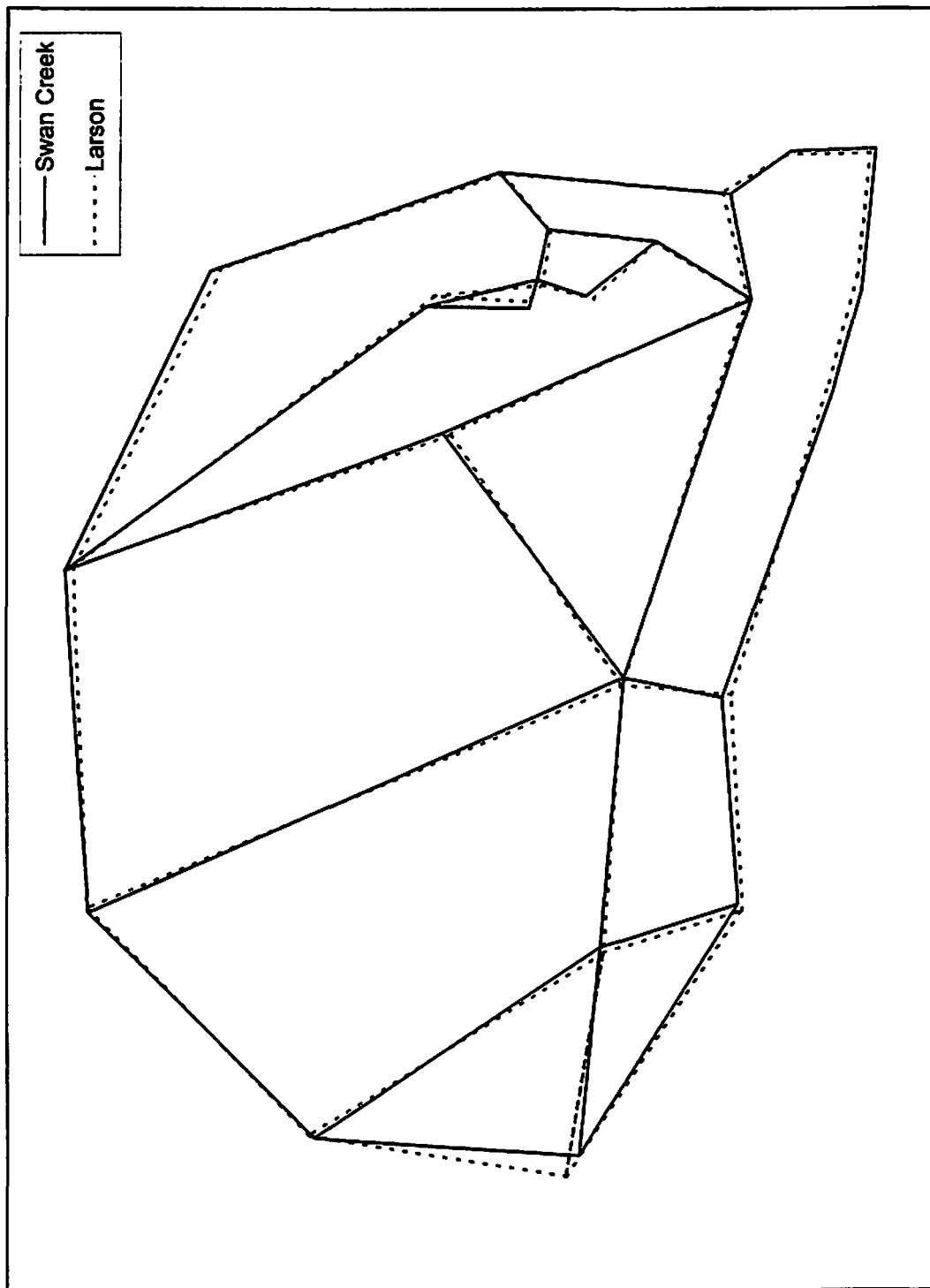


Figure 6.16. Consensus configurations for Swan Creek and Larson

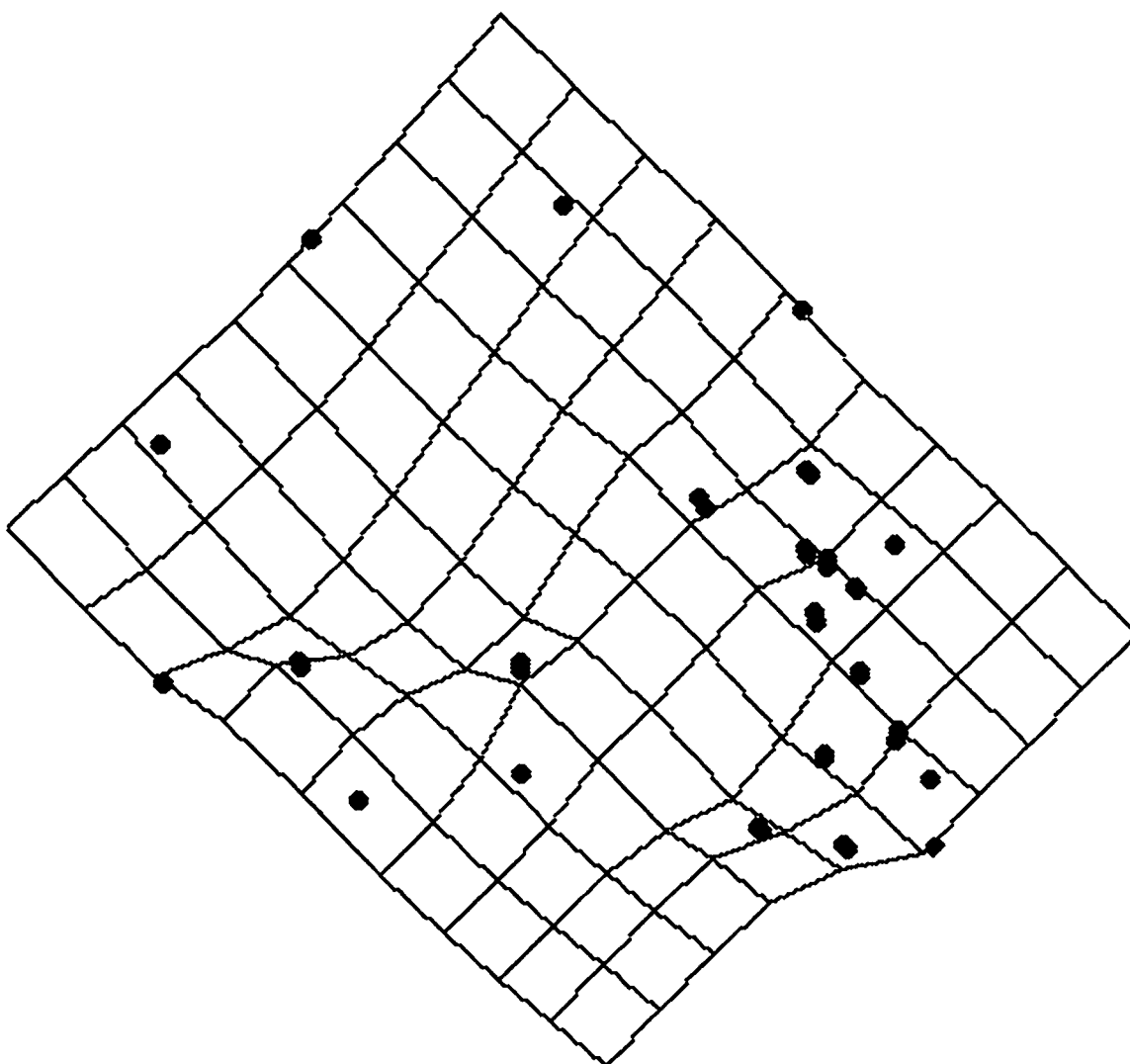


Figure 6.17. Thin-plate spline plot of mean configurations from Sully E and Sully A and D. Anterior is to the right and superior is to the top of the page.

fairly unaltered. Overall the Sully A and D consensus is longer, both anteriorly and posteriorly, than the Sully E mean. However, the Sully E mean appears to have greater vault height posterior to bregma which also includes the inferiorly positioned basion and opisthion which reflects greater cranial base height. The wireframe overlay plot of the two mean configurations shown in Figure 6.18 depicts these average differences between the two groups.

In addition to the geographical differences among the sites under investigation there are temporal and cultural divisions. Using these parameters in conjunction with geography may provide insights into the morphological variation present across space and time. The Bad River sites are located on the west (right) bank of the Missouri River and form a loose cluster on the canonical plot. In order to investigate what differentiates them from the east (left) bank populations, the mean configuration from the combined Bad River sites was transformed onto the Larson consensus configuration. The thin-plate spline plot shown in Figure 6.19 displays the result of this interpolation. Anterior stretching is present along the frontal and face and posterior stretching pulls out the posterior landmarks of the vault. This extension along the anterior-posterior axis of the vault indicates that the mean configuration for Larson exhibits a longer vault due to differences along both ends of that axis. Slight inferior stretching along the cranial base indicate that the Larson configuration exhibits greater cranial base as well as overall vault height which is unexpected for this comparison. The overlay plot of the two mean configurations employed in the thin-plate spline shown in Figure 6.20 confirms these observations.

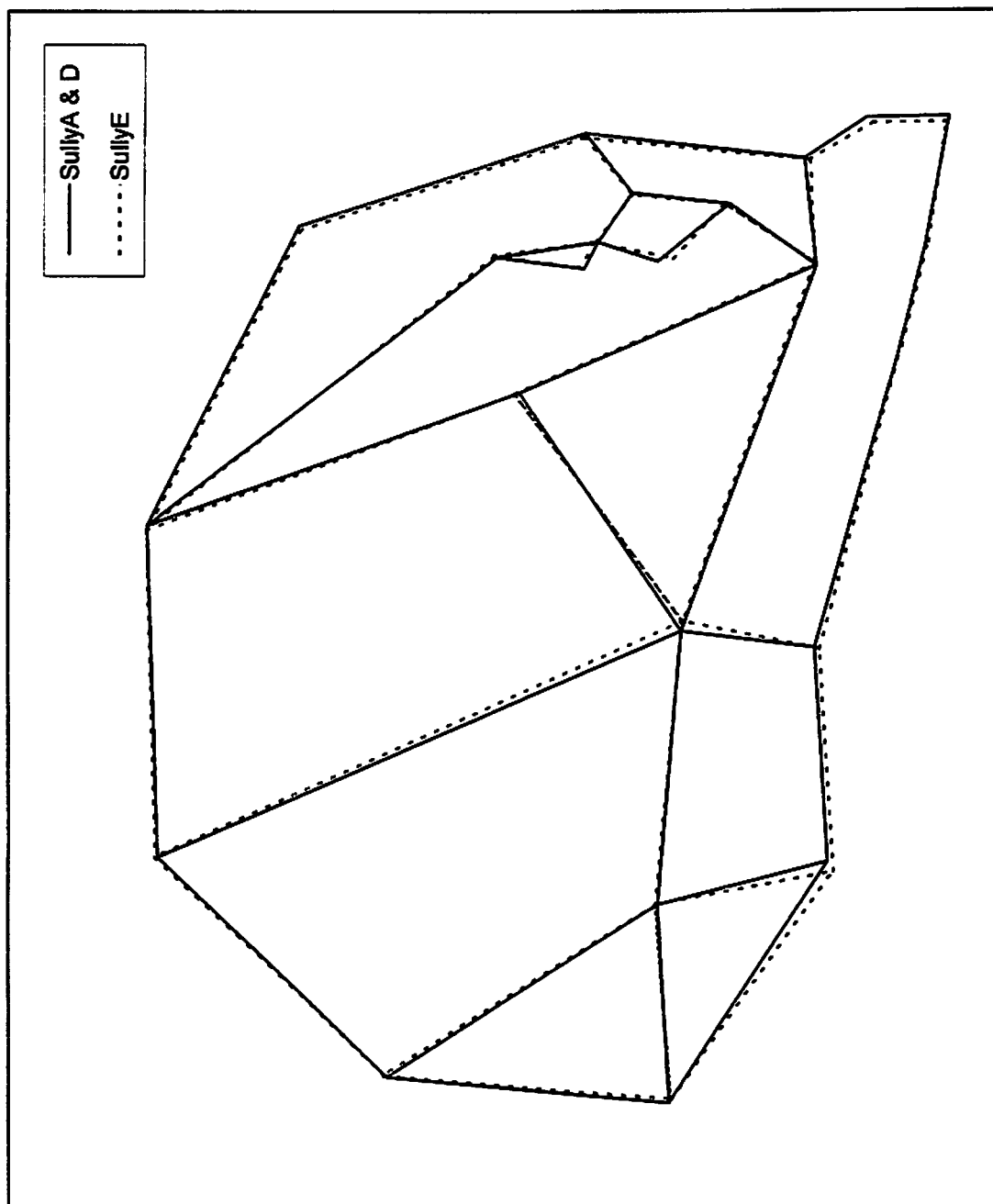


Figure 6.18. Consensus configurations for Sully A & D and Sully E

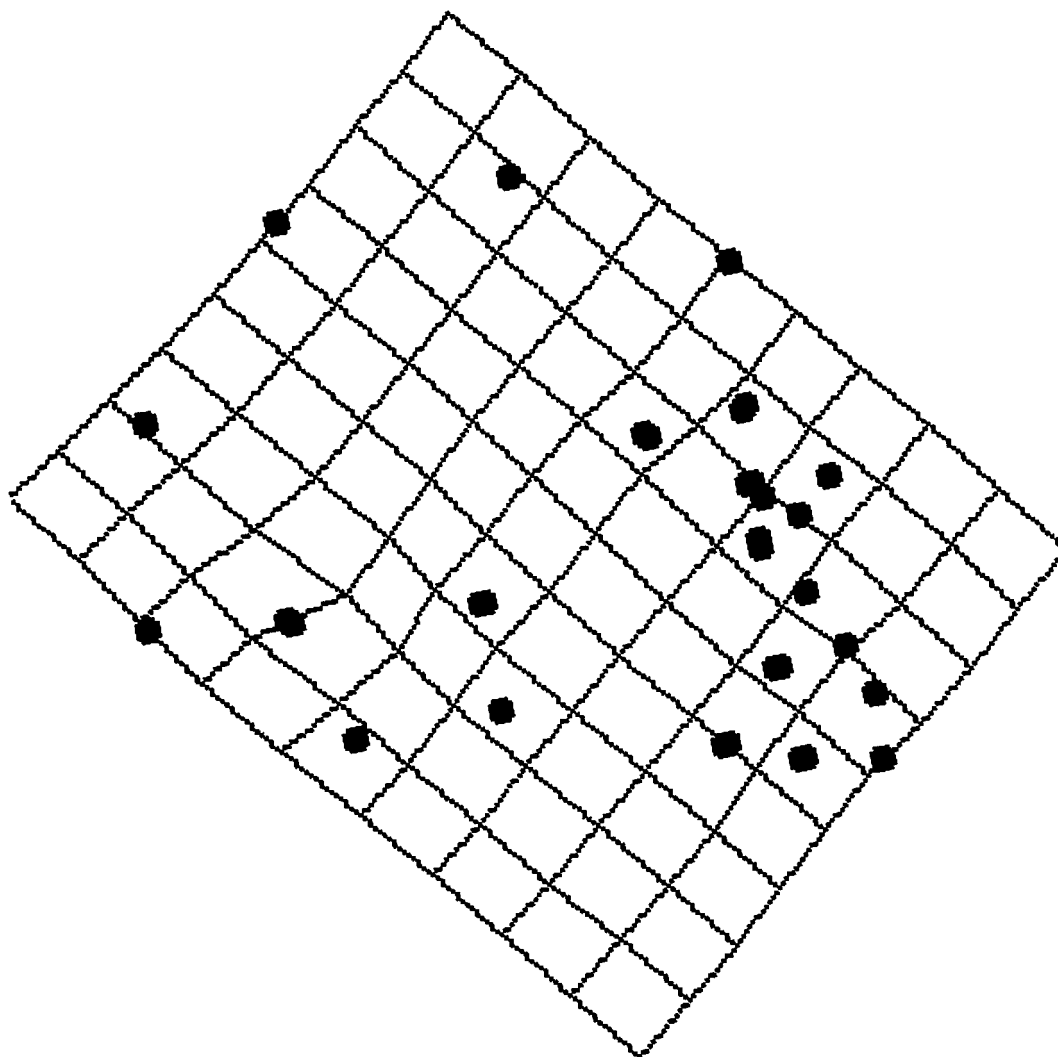


Figure 6.19. Thin-plate spline of mean configurations from the Bad River sites and Larson. Anterior is to the right and superior is to the top of the page.

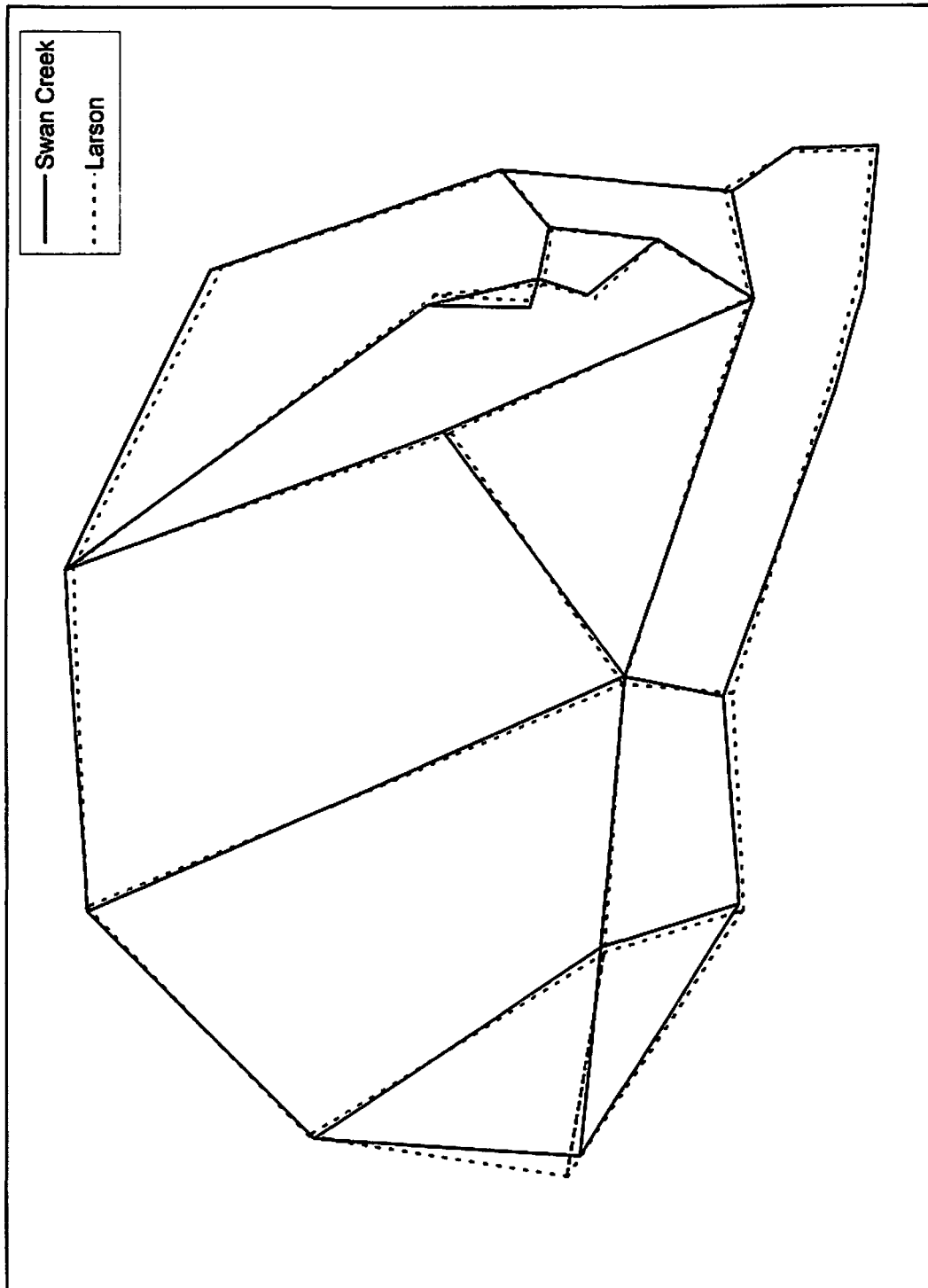


Figure 6.16. Consensus configurations for Swan Creek and Larson

A comparison of early sites from the northern and southern aspects of the Middle Missouri region seems appropriate based on the canonical plot. Both the Early South and Early North sites are located along the east (left) bank of the Missouri River and are considered to be La Roche based on archeological evidence; however, the canonical plot indicates that there are differences between the sites. The thin-plate spline plot shown in Figure 6.21 depicts the transformation of the Early South configuration onto the Early North configuration. Compression is evident at midfrontal while superio-posterior stretching at postoccipital reflects the greater posterior length of the vault for the Early North mean. Inferior stretching along the cranial base indicates greater base height for the Early North mean. These differences can be observed in Figure 6.22 which shows the mean configurations for the two groups overlayed. Overall, differences in the vault morphology involve greater frontal curvature for the Early South consensus while the Early North consensus is longer due to posterior extension of the occipital.

A comparison of the Early North configuration with that of Larson provides insight into the morphological differences present within this geographical area through time. The thin-plate spline plot shown in Figure 6.23 depicts the mapping of the landmarks for the Early North configuration onto the Larson configuration. This interpolation results in anterior stretching at midfrontal and posterior stretching along the posterior aspect of the vault. Slight superior stretching is apparent along the superior aspect of the vault. These extensions indicate that the average Larson cranial vault exhibits greater vault length as well as greater vault height when compared to the Early North mean. These observations are supported by the mean configuration overlays shown

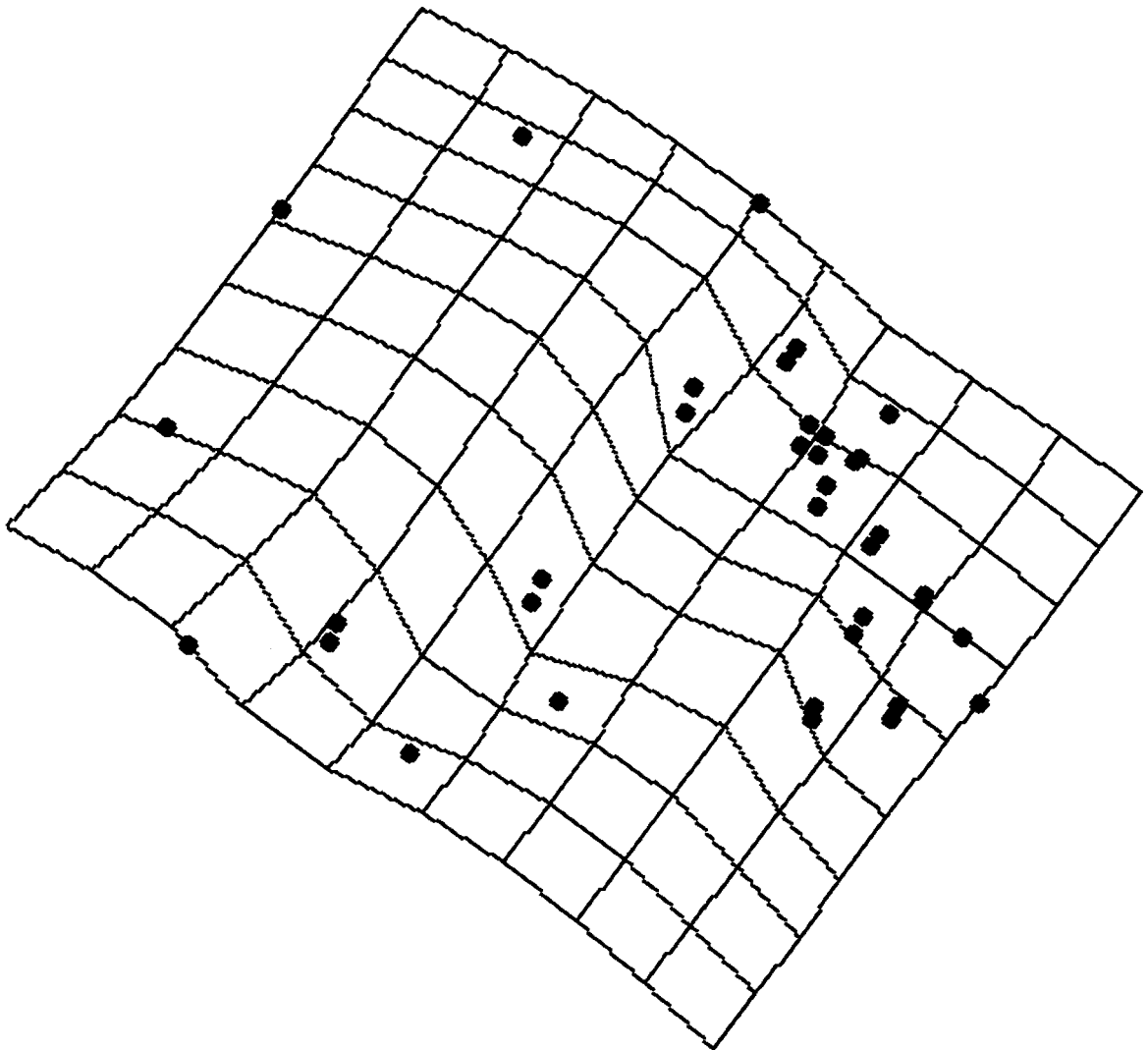


Figure 6.21. Thin-plate spline plot of mean configurations from the Early South and Early North group sites. Anterior is to the right and superior is to the top of the page.

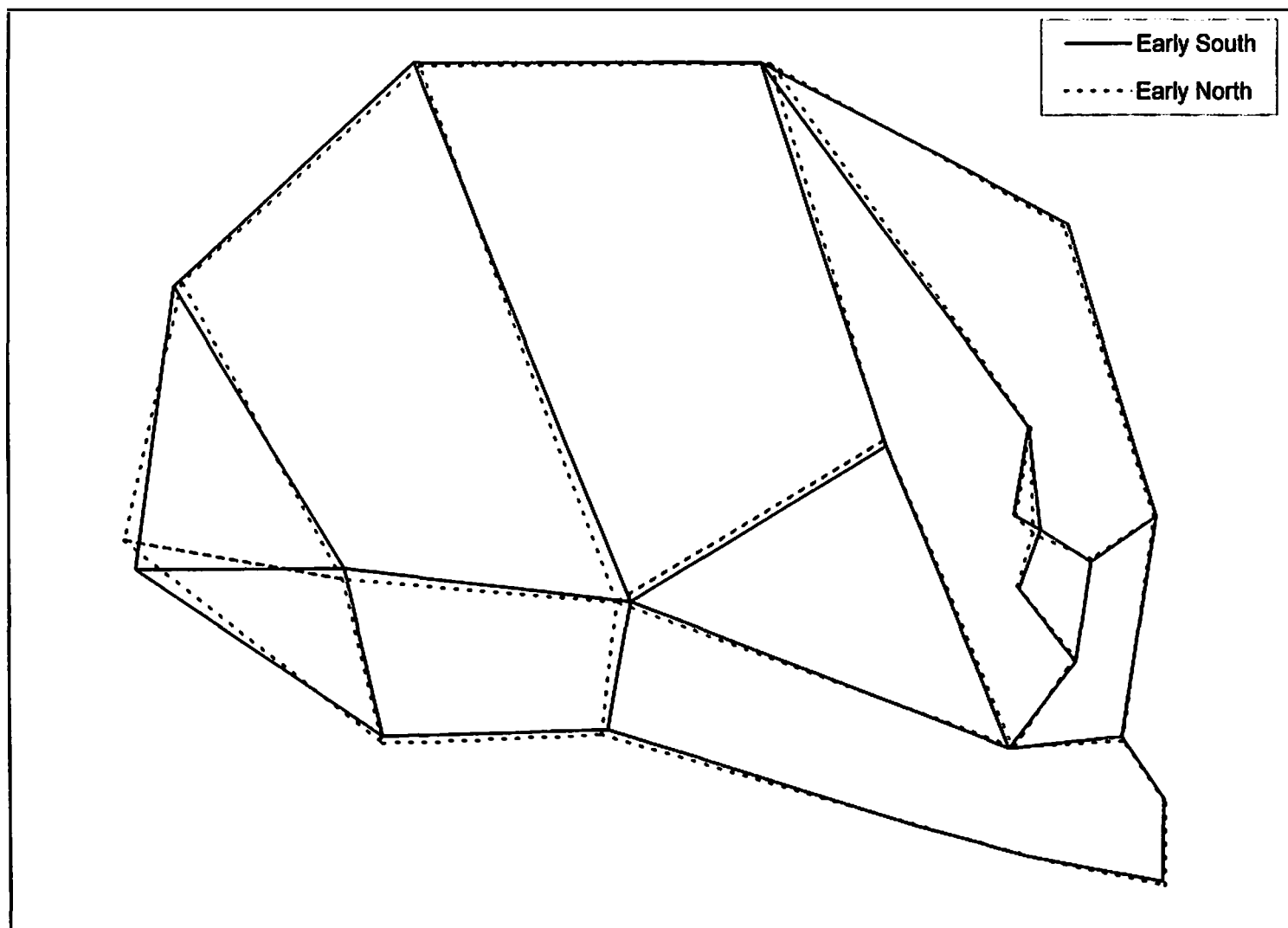


Figure 6.22. Consensus configurations for the Early South and Early North sites

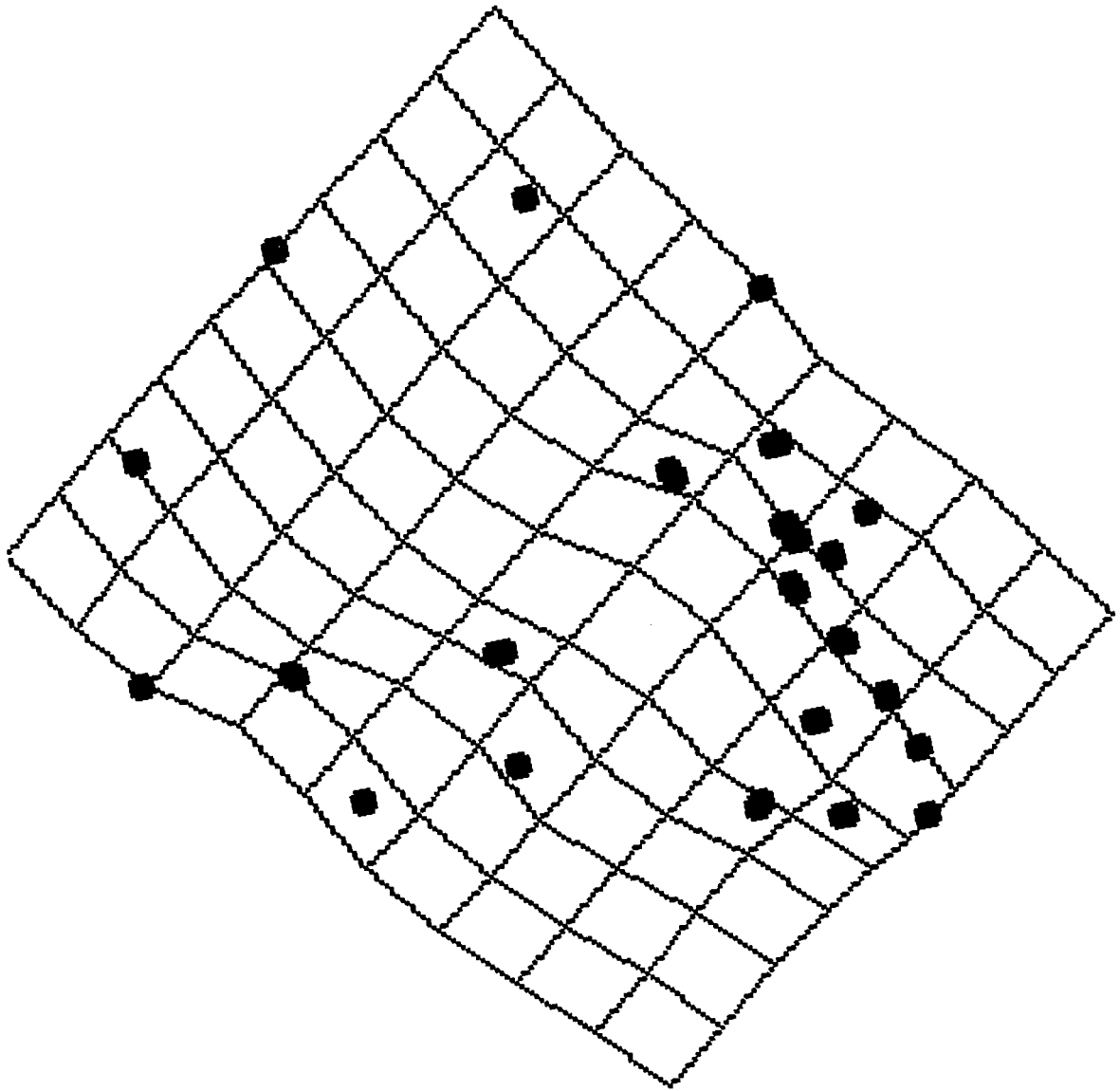


Figure 6.23. Thin-plate spline of mean configurations from the Early North group sites and Larson. Anterior is to the right and superior is to the top of the page.

in Figure 6.24. The greater length of the Larson configuration is expected based on prior research; however, the greater height of the Larson mean when compared to earlier sites from the area has not been recognized previously.

A corresponding comparison involves the Early South group and Larson which involves both geographic and temporal dissimilarity. The plot shown in Figure 6.25 displays the results of a thin-plate spline transformation employing the Early South configuration as the reference and the Larson configuration as the target. There is little deformation evident among the facial landmarks and the anterior vault. Posterior stretching along the occipital can be observed along with corresponding stretching at the zygomatic roots (auriculares) and asterions reflecting the elongated parietals. This difference in vault length is supported by the mean configuration overlay plot shown in Figure 6.26 and seems to be the primary morphological difference between the two.

An interesting contrast to the previous geographical/temporal comparisons involves transforming the Larson configuration onto the Leavenworth configuration. Time depth is present as Leavenworth postdates the terminal occupation of Larson by approximately 70 years and while Leavenworth and Larson are both northern sites, they are located on opposite sides of the Missouri River. Studies have demonstrated that the Leavenworth sample is an amalgamation of Bad River and Le Beau phase descendants with individuals classifying as Le Beau comprising the largest percentage of the sample (Byrd and Jantz 1994). Therefore, it is not surprising that the interpolation from the Larson consensus to the Leavenworth consensus requires very little local shape change as Figure 6.27 illustrates. The consensus configuration overlay plot shown in Figure 6.28

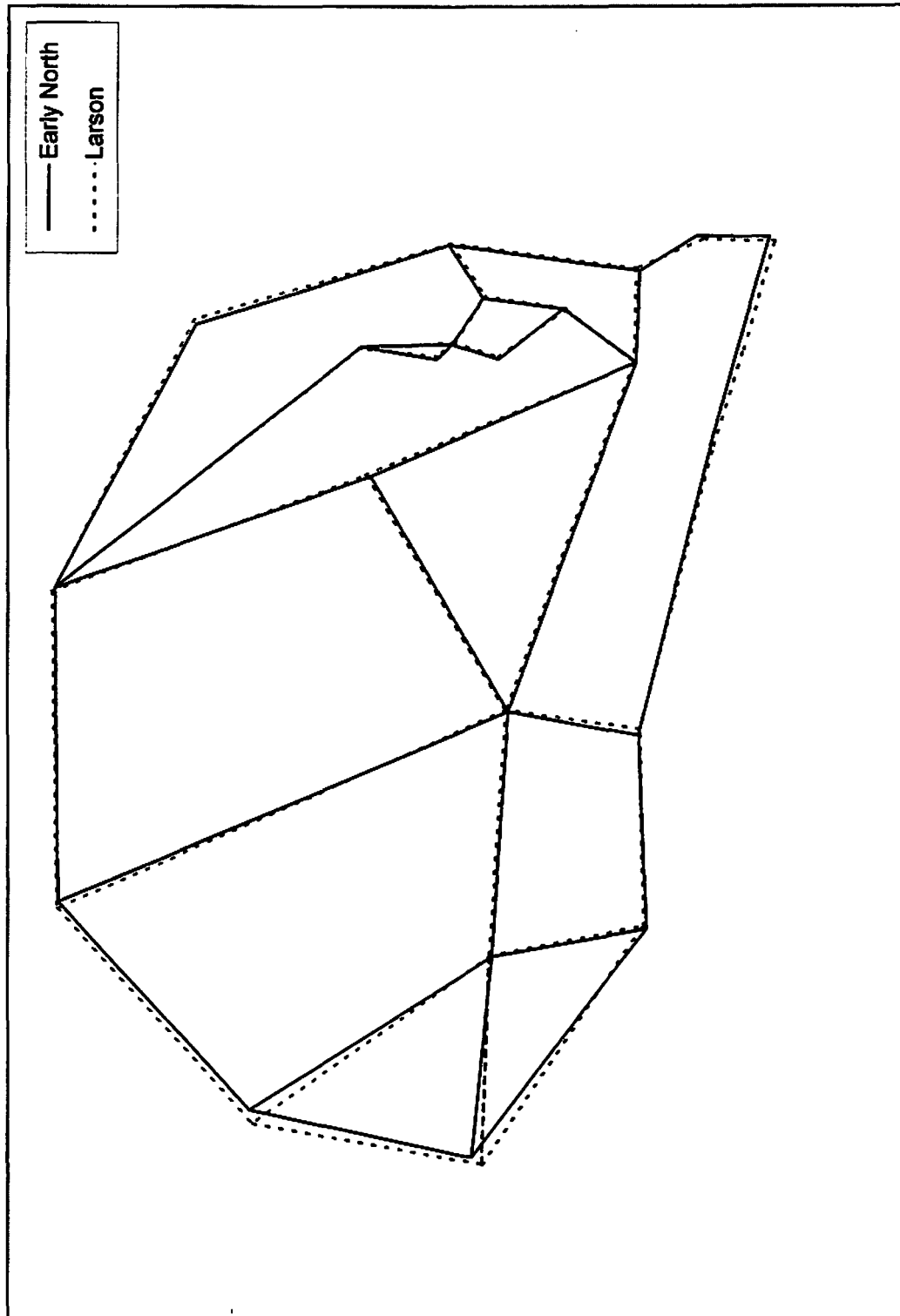


Figure 6.24. Consensus configurations for Early North and Larson

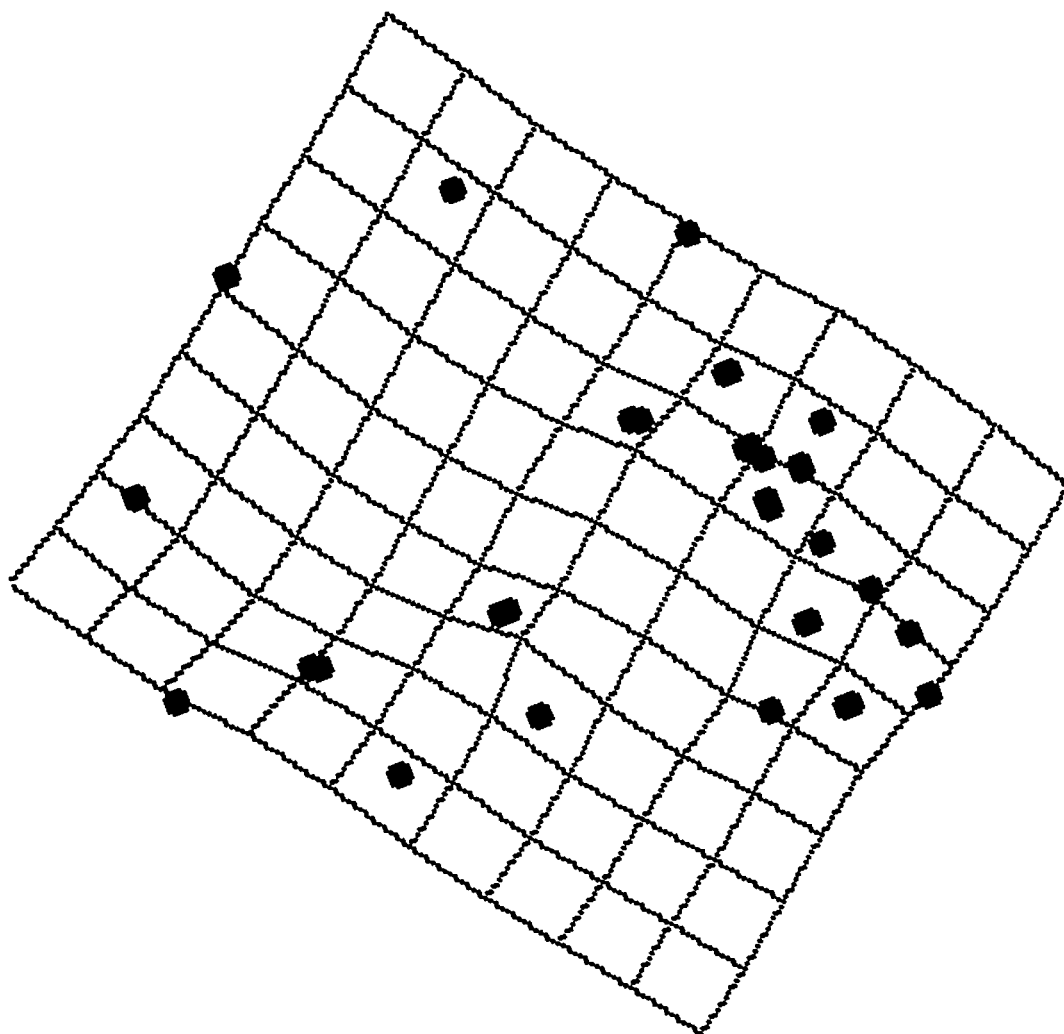


Figure 6.25. Thin-plate spline of the mean configurations from the Early South group and Larson. Anterior is to the right and superior is to the top of the page.

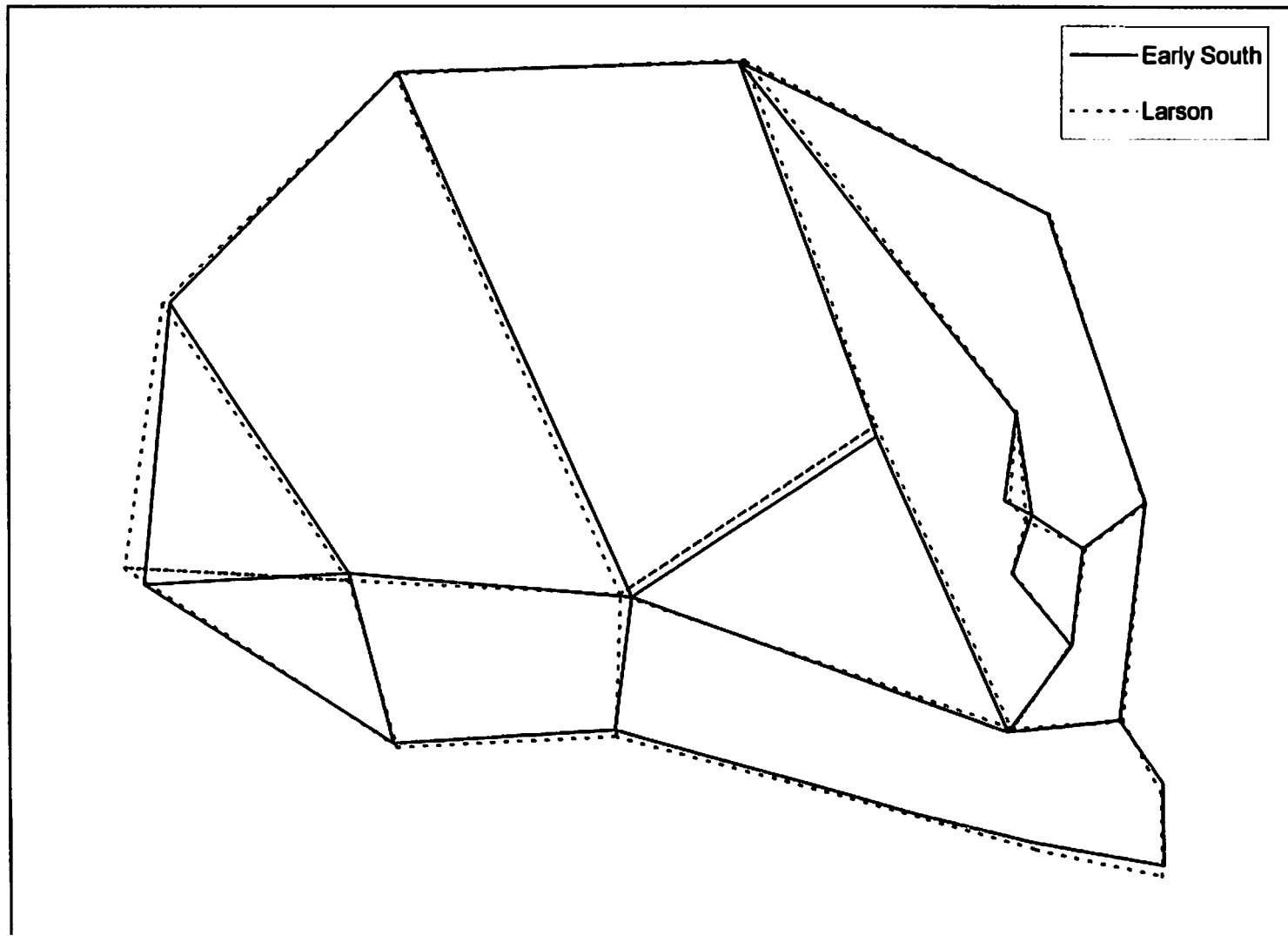


Figure 6.26. Consensus configurations for Early South and Larson

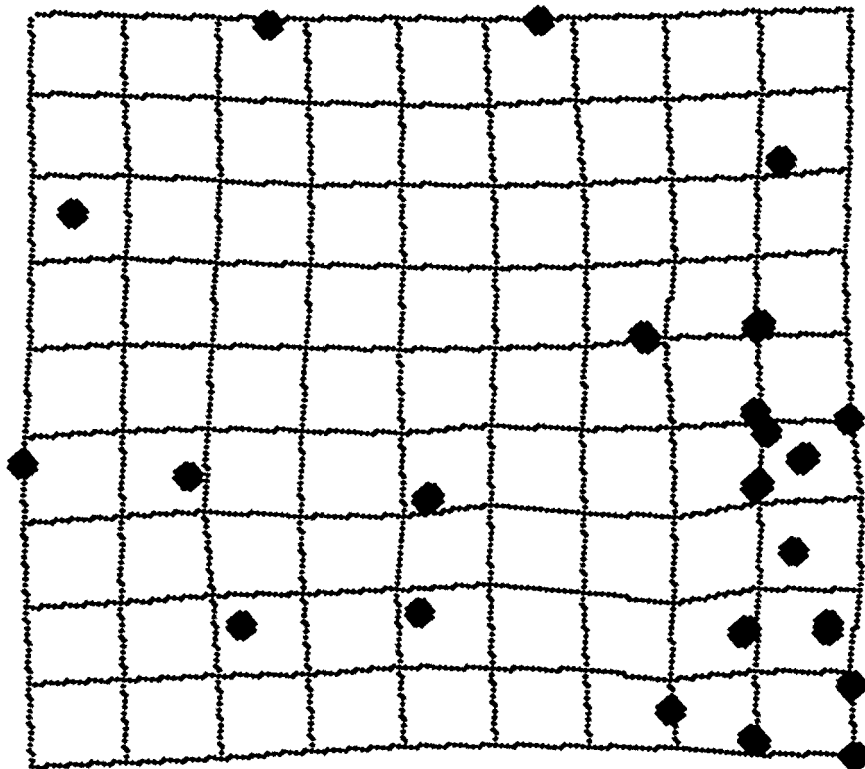


Figure 6.27. Thin-plate spline plot of mean configurations from Larson and Leavenworth. Anterior is to the right and superior is to the top of the page.

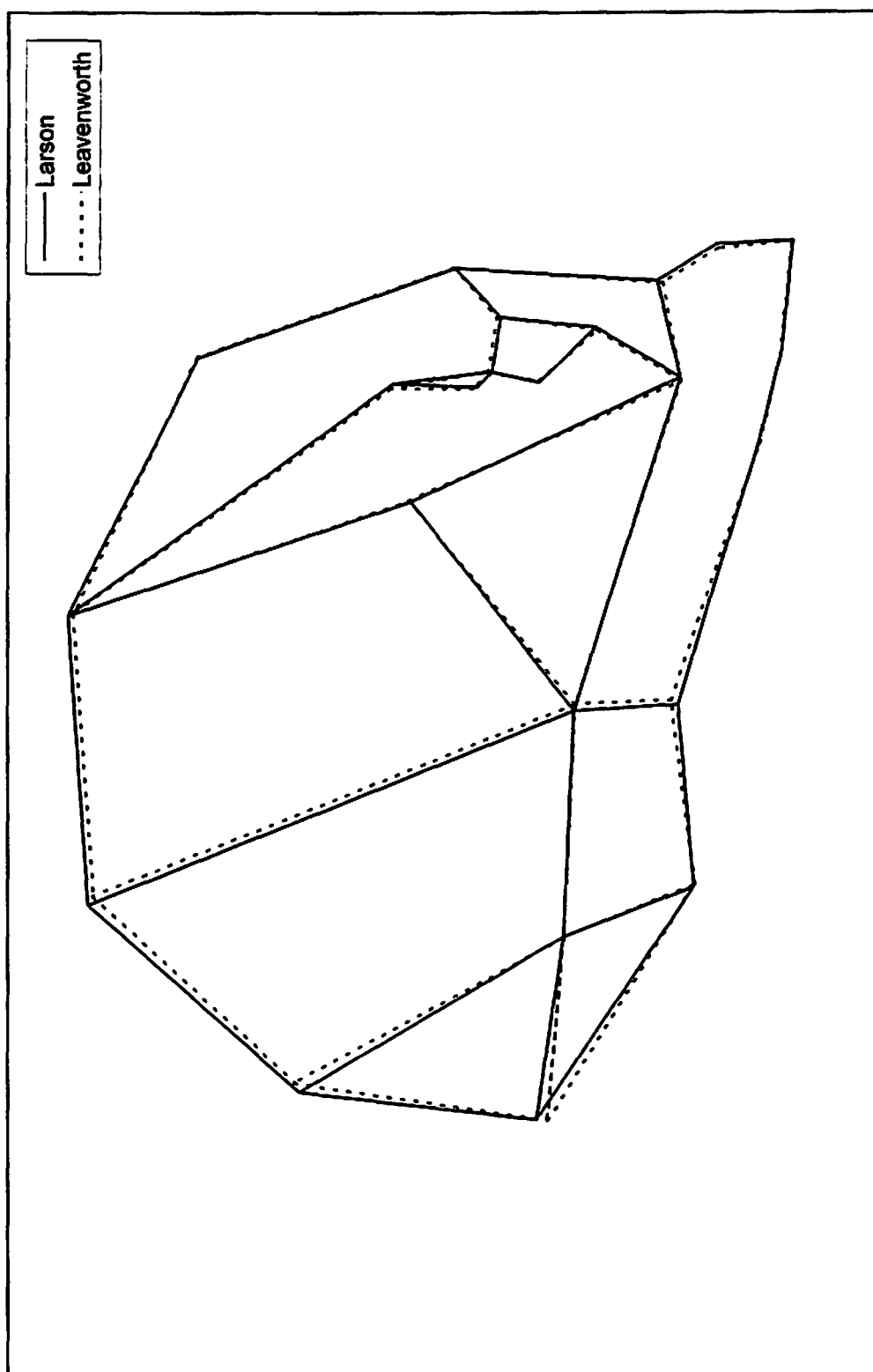


Figure 6.28. Consensus configurations for Larson and Leavenworth

depicts the slightly higher cranial vault of the Larson configuration which is the primary difference between the two forms.

A final comparison involves the interesting affinity of the Early South sites (Sully A and D) and the Bad River sites as depicted in the canonical plot and the biological distance matrix. While these groups of sites are both located on the southern aspect of the Missouri River, the populations that inhabited these villages were separated by the Missouri River and potentially by archaeologically recognized cultural differences. The closeness of these two site clusters suggests possible gene flow across the Missouri River and in spite of the cultural differences. Figure 6.29 depicts the thin-plate spline interpolation of the Early South configuration onto the Bad River configuration. Slight compression at midfrontal and posterior stretching at posterior occipital indicate that the Early South configuration has slightly greater frontal curvature while the Bad River mean is slightly longer at posterior occipital. Otherwise the differences between the two consensus forms is minimal as seen in Figure 6.30 which suggests that gene flow did occur between these two geographic and cultural areas.

An overview of the bending energy and Procrustes distance calculated for each TPS transformation is provided in Table 6.11. Comparisons across the Procrustes distance values reflect the overall degree of similarity between configurations and are proportionately similar to the biological distances derived in the canonical discriminant analysis. The bending energy values reflect the amount of energy necessary to perform the non-affine or localized deformations of the thin-plate spline transformations. The

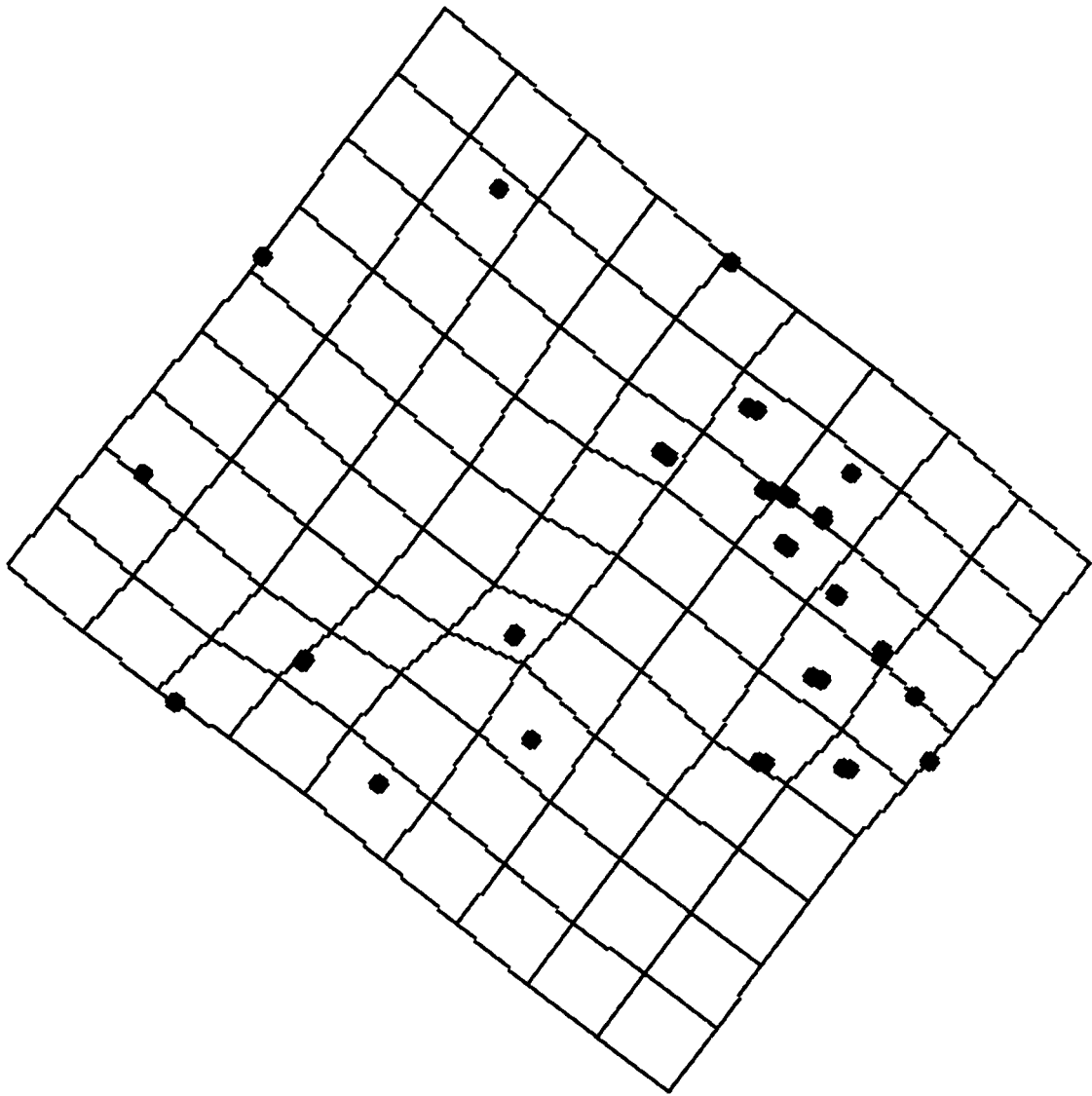


Figure 6.29. Thin-plate spline of mean configurations from the Early south sites and the Bad River sites. Anterior is to the right and superior is to the top of the page.

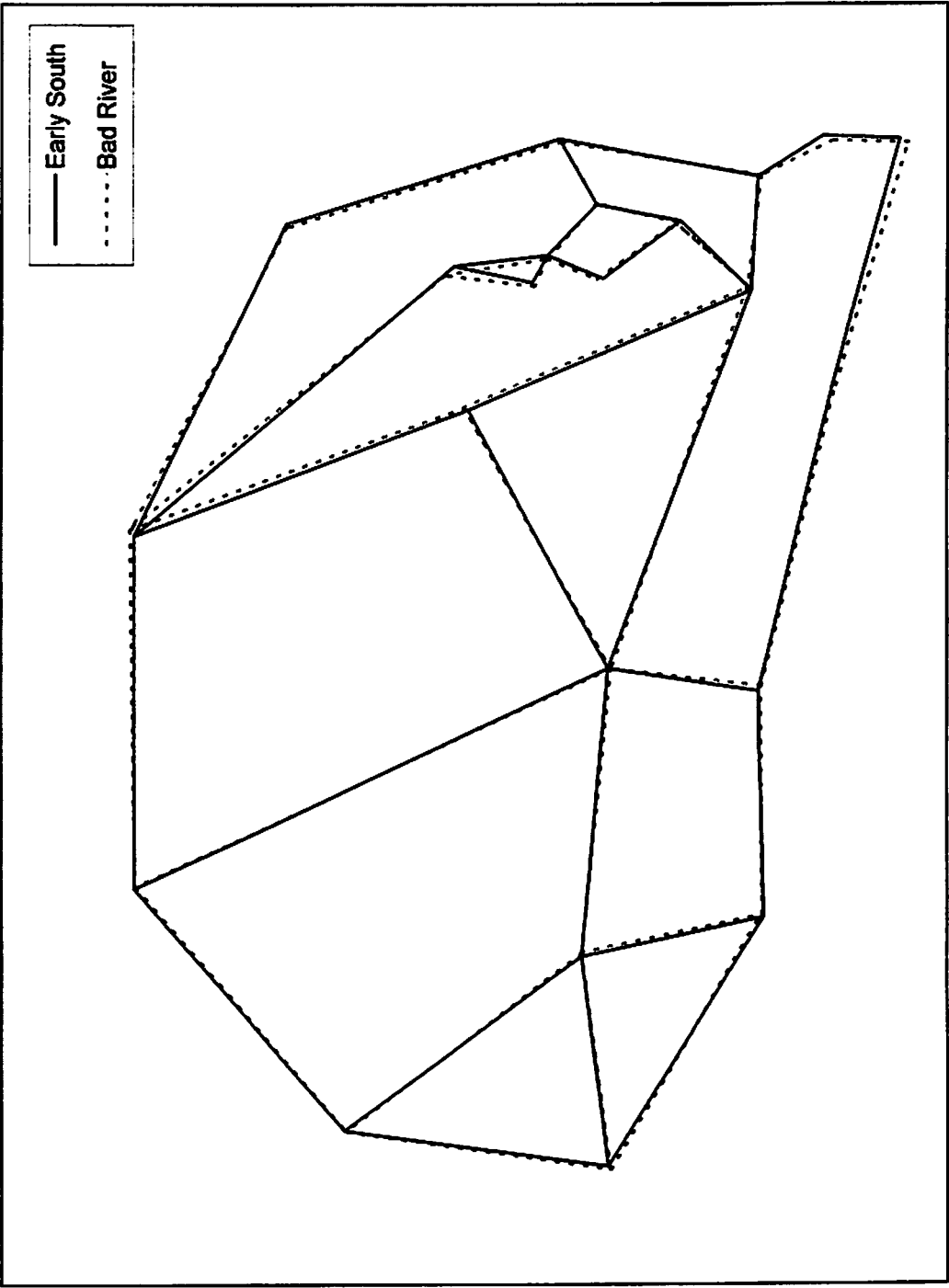


Figure 6.30. Consensus configurations for Early South and Bad River

Table 6.11. Bending energy and Procrustes distance from the thin-plate spline analysis.

Comparison		Bending Energy	Procrustes Distance
Reference	Target		
Mobridge F1&3	MobridgeF2	1.85236	0.03532
Swan Creek	Larson	1.92354	0.03471
SullyE	Early South	8.24090	0.02439
Bad River	Larson	0.94440	0.02133
Early South	Early North	6.28512	0.03484
Early South	Larson	1.27200	0.02354
Early North	Larson	2.13599	0.03538
Larson	Leavenworth	0.81066	0.01684
Early South	Bad River	0.61928	0.01763

transformations that required greater bending energy correspond to small scale differences. Therefore configurations that are overall quite similar with only differences among features associated with only a few landmarks will actually require a greater bending energy to accomplish the interpolation than those with large scale differences.

In summary, much of the variation among the individuals from the various sites attribute to the Arikara is due to shape related sexual dimorphism. That sexual dimorphism without size is the greatest component of variation argues for the biological homogeneity of these individuals and their attribution to a single Native American tribe. The very small eigenvalues and total variance values also argue for the low degree of variation present among these samples. The variation in cranial morphology that is present follows a pattern of isolation by distance. When the geographical distance separating two site is small, the biological distance between the skeletal sample recovered from those sites is generally small. Conversely, when the geographic distance separating two sites is large, then the biological distance between the samples from the sites tends to also be large. Simply put, samples from sites that are located close together tend to be more similar to one another and samples from sites that are far apart tend to be less similar to one another. Evidence for this pattern is found in the results of the canonical discriminant analysis as illustrated by the plot of the first two canonical variates and the positive correlation between the biological and geographic distance matrices. The negative temporal correlation implies that migration was occurring among the sites.

The analysis of the two dimensional configurations provides information about the morphological patterns behind the similarities and differences among the groups. The

southern sites (Sully components and the Bad River sites) share a common morphological pattern with Sully E being the most differentiated. When compared to northern sites, the southern morphological pattern is more anterior and inferior at posterior occipital reflecting a shorter cranial vault. Differences in cranial vault length is also present between the early and later southern sites but the location of posterior occipital on the longer Larson configuration is inferior, rather than superior as we saw with the northern/southern comparisons. This inferiorly directed movement of posterior occipital is carried through to the Leavenworth which exhibits the most posterior and inferiorly located landmark. Much of the variation in vault height as measured between basion and bregma is due to location of basion; however, there is no apparent temporally ordered decrease in cranial vault height until Leavenworth. The shorter vault height of the mean configuration from Leavenworth is due to both the inferior position of the superior vault landmarks as well as the superior location of basion and opisthion. There is also no apparent temporal pattern associated with frontal curvature as a more arching frontal is present among both the early southern sites and later northern sites such as Larson and Leavenworth.

These patterns of morphological variation reflect the geographical distances that separate the sites. The sites sharing a common geographical area share similar landmark locations and the differences across space and time are mainly associated with the locations of posterior occipital, basion and opisthion. An increase in vault length is evident from south to north and through time. However, a considerable decrease in cranial vault height is not apparent until the historically documented Leavenworth site.

CHAPTER 7

DISCUSSION AND CONCLUSIONS

Noted in previous studies (Jantz 1977, Owsley et al. 1981) and emphasized here is the overall similarity among individuals attributed to the Arikara. There are significant differences that can be used to distinguish among the groups in this study; however, this discrimination is tenuous with relatively high rates of misclassification for individual crania in the jack-knife allocation procedure. The similarity in cranial morphology supports the attribution of all these sites to the Arikara tribe, documented historically only at Leavenworth, and testifies to continuing migration between the populations that served to maintain the genetic commonality. Additionally, much of the variation that is present can be attributed to sexual dimorphism as the first principal component accounting for almost 9% of the total variation appears to represent shape related sex differences.

A recurrent theme in previous analyses of biological variability among the Arikara is the presence of temporally patterned change in cranial morphology. In particular, these studies demonstrated that through time the dimensions of cranial vault length and face height increased while cranial vault height decreased. This more Mandan-like pattern was especially evident among the Leavenworth sample who exhibit the greatest cranial vault length and face height combined with the lowest vault heights. Some research also detected a geographic pattern to cranial morphology (Jantz et al. 1981, Key and Jantz 1981); however, it was overshadowed by the temporal trend.

The current study demonstrates that geographic distance is the primary factor in structuring biological variation as measured by cranial morphology. Konigsberg's (1990) model of isolation by geographic and temporal distance for subdivisions of a population practicing a fixed pattern of marital migration predicts a positive correlation between biological and geographic distance and a negative correlation between biological and temporal distance. The positive correlation between biological and geographic distance indicates that phenotypic divergence increases as geographic distance increases. The negative correlation between biological and temporal distance is due to the decrease in phenotypic divergence through time due to gene flow. The significant positive correlation for biological and geographic distance in this study conforms to the expectations of the model regarding isolation by geographic distance. The negative correlation between biological and temporal distance is expected but the lack of significance creates some uncertainty as to its import. Some factors that may be confounding the temporal correlation include: a lack of time depth in the present study (approximately 250 years); the possibility that selection is operating on cranial morphology; the probability that genetic drift is operating on these populations with unknown consequences for cranial morphology; and the indications that external gene flow may be affecting cranial morphology particularly in the later samples. Konigsberg's (1990) model was not designed to take such factors into account.

The emergence of the geographic pattern is most likely due to the inclusion of Extended and Post-Contact Coalescent sites from the southern end of the range for protohistoric and historic Arikara providing a more balanced geographic picture.

Additionally, controlling for some temporal differences in many of the larger series also contributes to a better understanding of the variation present among these samples. While a temporal trend in morphology is indicated in the canonical and thin-plate spline transformation plots, it is not as important as geography for the patterns of variation for this larger sample.

Geographic, Temporal and Cultural relationships among Arikara sites

Figure 7.1 is a plot of Bad River, Larson, Northern La Roche, Sully and Mobridge F2 components along canonical variates (CV) 1 and 2 and depicts important information about the relationship of Mobridge F2 to the other groups. Individuals from Mobridge F2 are scattered across the plot with no distinct cluster present. This wide distribution of individuals from Feature 2 at Mobridge indicates it is not a coherent sample and that individuals from different temporal periods, if not from different cultural affiliations, are present. Owsley and coworkers (1982) noted that the burials Bass excavated from Feature 2 in 1970 contained a much higher percentage of Euro-American trade goods than the 1971 Ubelaker Feature 2 excavations. Fifteen burials excavated by Stirling in 1923 are also included in the Feature 2 sample, which may contribute to the greater heterogeneity of the sample. These individuals were included in the Feature 2 sample based on re-evaluations of Stirling's field notes suggesting that the burials were excavated from the area later identified as Feature 2 (Billeck 2000, personal communication). However, the evidence from craniometrics suggest that these burials

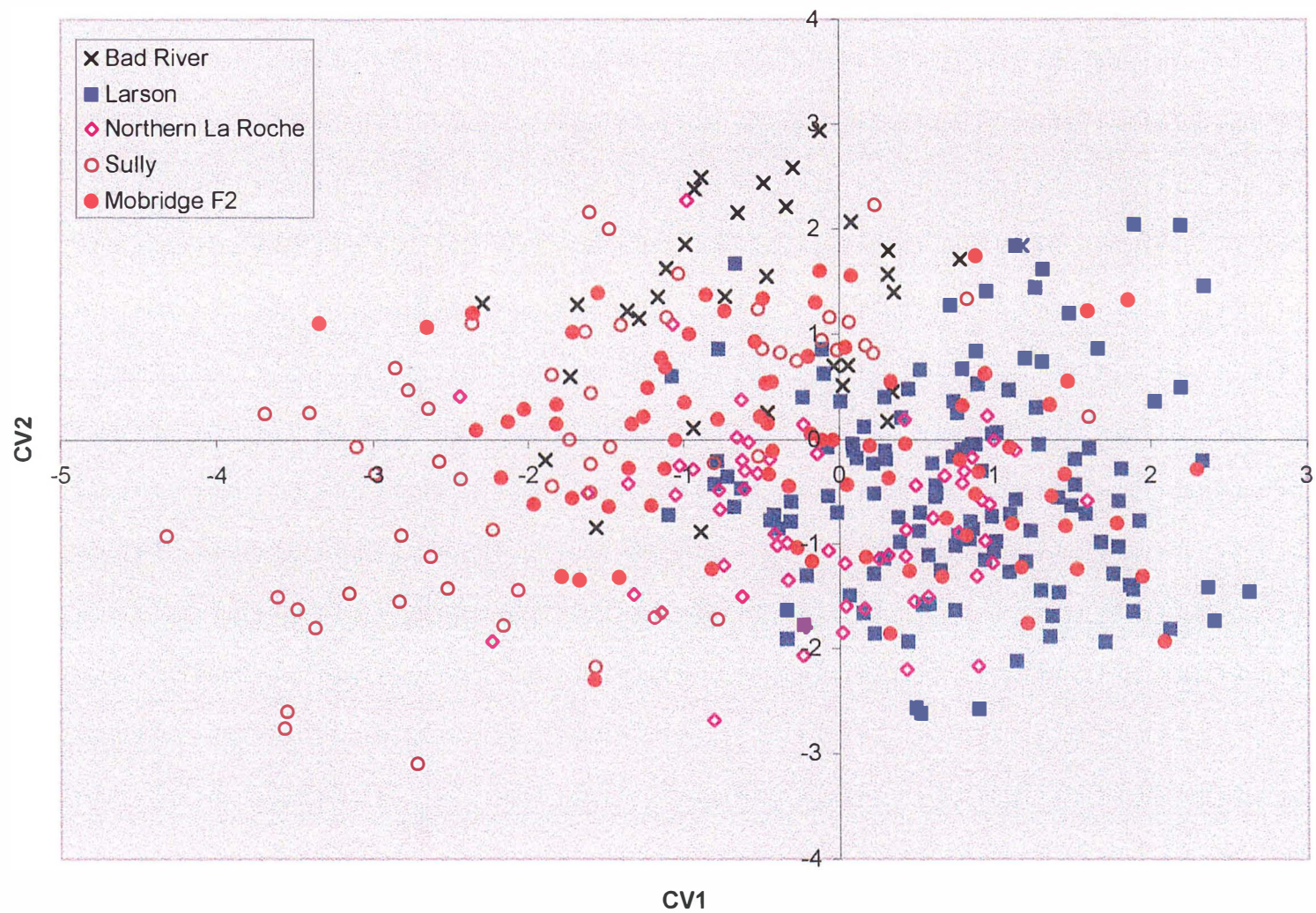


Figure 7.1. Canonical plot of Bad River, Larson, Northern La Roche, Sully and Mobridge F2 components

may not be from Feature 2. Owsley and coworkers (1981) compared cranial measurements from the Stirling burials with the Feature 2 burials excavated by Bass and Ubelaker as well as the burials from Features 1 and 3. The burials from Feature 1 and 3 cluster together in a distinct separation from the Feature 2 burials and the Stirling burials appear much more similar to the Feature 1 and 3 cluster. Nevertheless, the comparatively small number of Stirling burials (15 out of 92) does not single-handedly account for the wide-ranging distribution of individuals from Feature 2. I attribute most of this variation to temporal differences between the burials excavated under the direction of Bass and Ubelaker.

Individuals from Leavenworth are compared to Bad River, Larson, Northern La Roche and Sully components along canonical variates 1 and 2 in Figure 7.2. As expected, Leavenworth individuals seem to fall into both the Le Beau and Bad River clusters reflecting the presence of individuals from both cultural divisions, which is similar to the findings of Byrd and Jantz (1994) and McKeown and Konigsberg (2000). The greater number of Leavenworth individuals within the Le Beau cluster is to be expected as a higher percentage of Le Beau phase descendants were detected by Byrd and Jantz (1994) in the Leavenworth sample.

Components from the Bad River and Northern La Roche sites, Larson and the burial areas of Sully are compared in the canonical plot shown in Figure 7.3. The components of Sully, except for SullyB, form a loose cluster in the lower left quadrant with many individuals from Sully A spilling over into the Bad River cluster located in the

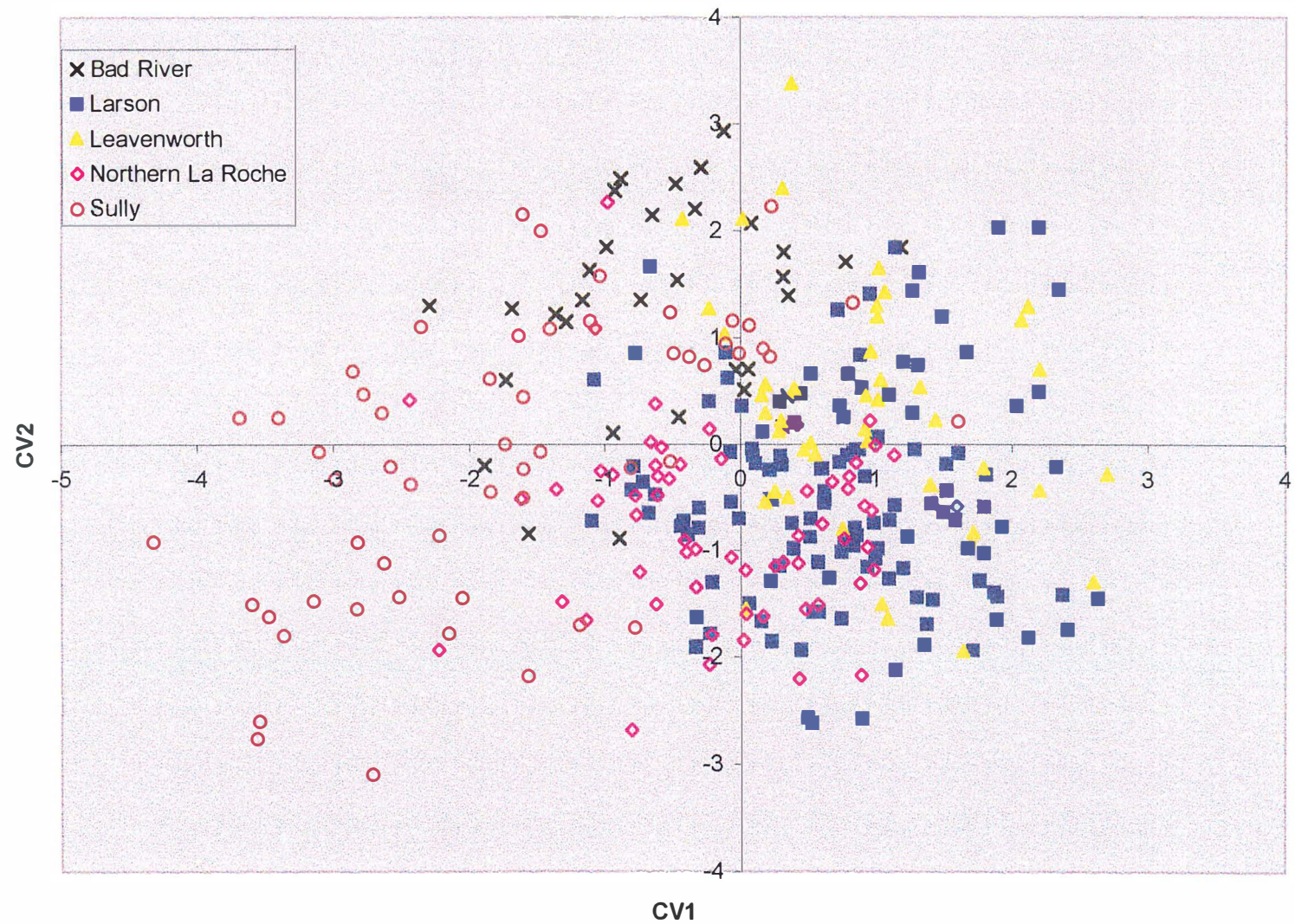


Figure 7.2. Canonical plot of Bad River, Larson, Leavenworth, Northern La Roche and Sully components

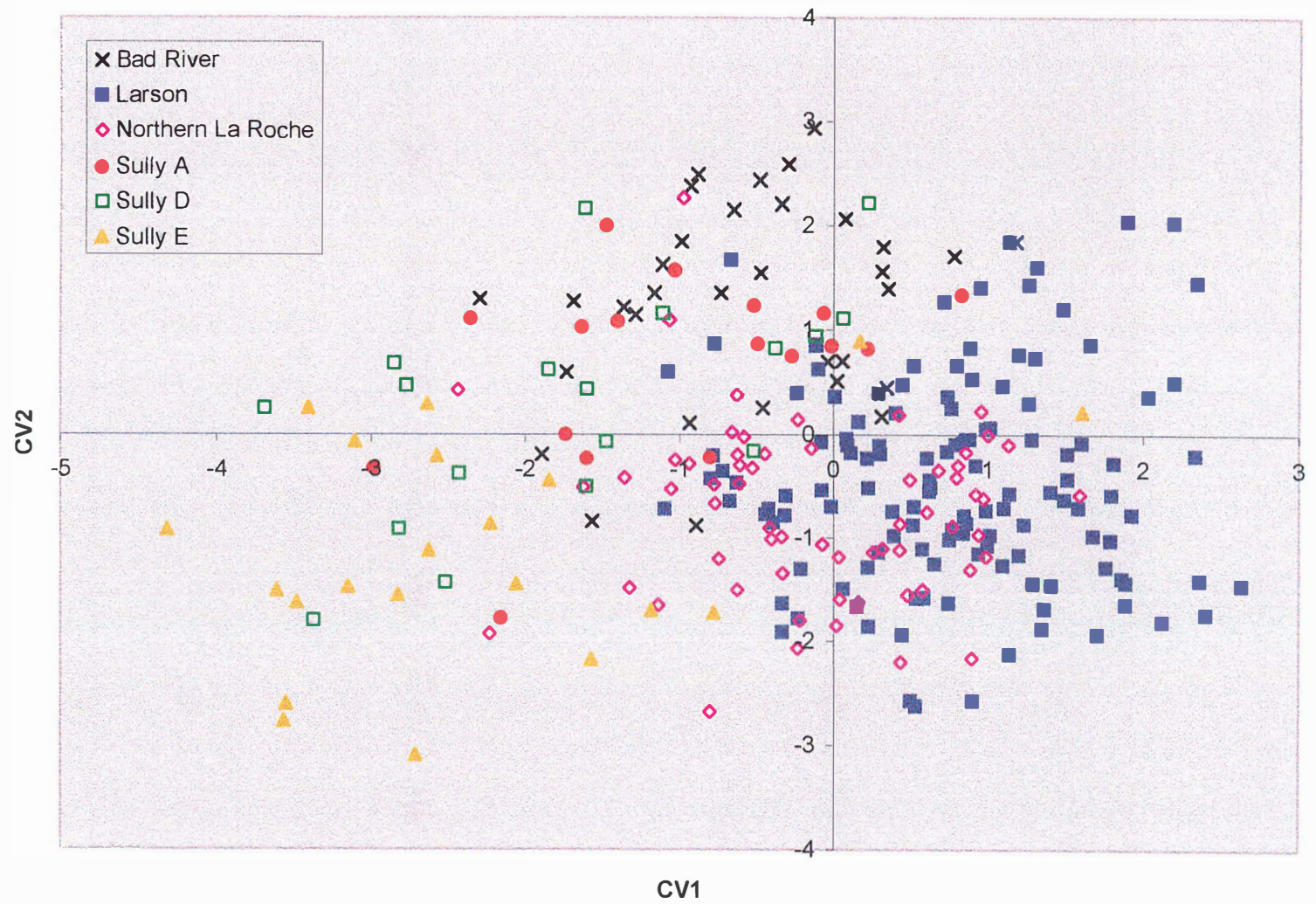


Figure 7.3. Canonical plot of Bad River, Larson, Northern La Roche components and Sully burial areas A, D and E

upper left quadrant and extending into the upper right quadrant. The sites attributed to the Early North group, Rygh, Mobridge F1 and Mobridge F3, cluster along the negative branch of CV2 sandwiched between the Le Beau sites in the lower right quadrant and the Sully components in the lower left quadrant.

The proximity of the northern La Roche cluster and the later northern sites attributed to the Le Beau phase suggests strong biological continuity through time in the Grand-Moreau region. Relative to canonical axes the Early North cluster is centered on zero for CV1 along the negative branch of CV2 and the Le Beau individuals form a cluster that runs oblique to CV1 as it extends from the lower right quadrant into the upper right quadrant. These positions relative to the canonical axes indicate that change through time for the northern La Roche sites to the northern Le Beau sites (except Swan Creek) would involve an increase in upper vault height and a decrease in cranial base height associated with an overall decrease in vault height as well as an increase in face height. This may explain the significant temporal trend in cranial vault dimensions detected by previous studies (Jantz 1970, 1972, 1973, Key 1983, Key and Jantz 1981, Lin 1973, Owsley et. al. 1981). Additionally, the presence of several Larson individuals located in the negative range for CV1 within the Early North cluster suggests that temporal variation may be present at Larson with some burials associated with a La Roche occupation.

While relatively diffuse in overall distribution, there is significant overlap between the Sully components A and D and the Bad River cluster. In particular, many individuals from Sully A fall well into the Bad River range and individuals from Black

Widow Ridge and Cheyenne River are present in the Sully cluster indicating a high degree of similarity. Jantz (1977) makes reference to this affinity, and it is evident from this data set that neither the Missouri River nor cultural differences were major barriers to gene flow among these sites.

A critical point must be made regarding the cultural affiliation of burial area E from Sully. While this component is considered to be Le Beau, this attribution is clearly not warranted on the basis of biological affinity. Sully E consistently appears as an outlier and based on generalized distance estimates, these individuals are most similar to the Sully D component and are distinctly not like the Le Beau individuals. However, Sully E does not appear to be a Bad River phase component either, raising the question as to what group is represented by the burials from Area E at Sully. Previous research regarding the affinities of sites attributed to the Arikara that include other Northern and Central Plains samples (Jantz et al. 1981) have found that individuals from the Sully site misclassify with Pawnee, Mandan and St. Helena samples. The morphological pattern associated with the general location of most Sully E individuals includes shorter faces and overall higher cranial vaults composed of higher cranial bases and lower upper vault heights. Several individuals appear to be outliers even from the diffuse Sully E cluster; perhaps these individuals with the extreme expression of the above described morphology represent Initial Coalescent burials. Further support for this hypothesis is found in Owsley and Jantz (1978) where the females from burial area E were found to similar to females from the Central Plains Tradition Murphy site (25DK9), a St. Helena phase site in northeastern Nebraska. The craniometric analysis of Initial Coalescent phase

individuals from Crow Creek indicates that they are morphologically most similar to the St. Helena sites included in the analysis (25DK9 and 25DK13) followed by early Arikara sites such as Mobridge, Rygh and Sully (Willey 1990, Willey and Emerson 1993). Taken together, this evidence indicates that the presence of Initial Coalescent burials at Sully E is highly probable. The relative position of the overall sample argues against a Le Beau affiliation and instead suggests that most of the burials can be attributed to a La Roche phase component. The presence of Euro-American items in association with several Sully E burials could be accounted for by intrusive Post-contact Variant burials. The existence of such burials is supported by two individuals from Sully E included in this study that are located well within the Le Beau and Bad River ranges on the CV plot.

Turning to other sites that do not conform to the archaeologically assigned cultural units, Swan Creek and Nordvold 2&3 do not cluster with their respective culturally assigned groups, Le Beau and La Roche as shown in Figures 7.4 and 7.5. Instead they both primarily fall in the Bad River cluster. Two individuals from Swan Creek break from this pattern and are centrally located in the Le Beau cluster indicating that they most likely share biological affinity with the peoples of the Le Beau phase. However, most of the Swan Creek sample appears to affiliate with individuals from the Bad River phase sites, which does not necessarily seem improbable. While Swan Creek is located north of the Bad-Cheyenne region on the east (left) bank of the Missouri River, it falls well south of the cluster of sites in the Grand-Moreau region. This proximity would have made gene flow with the Bad River phase populations more likely. The

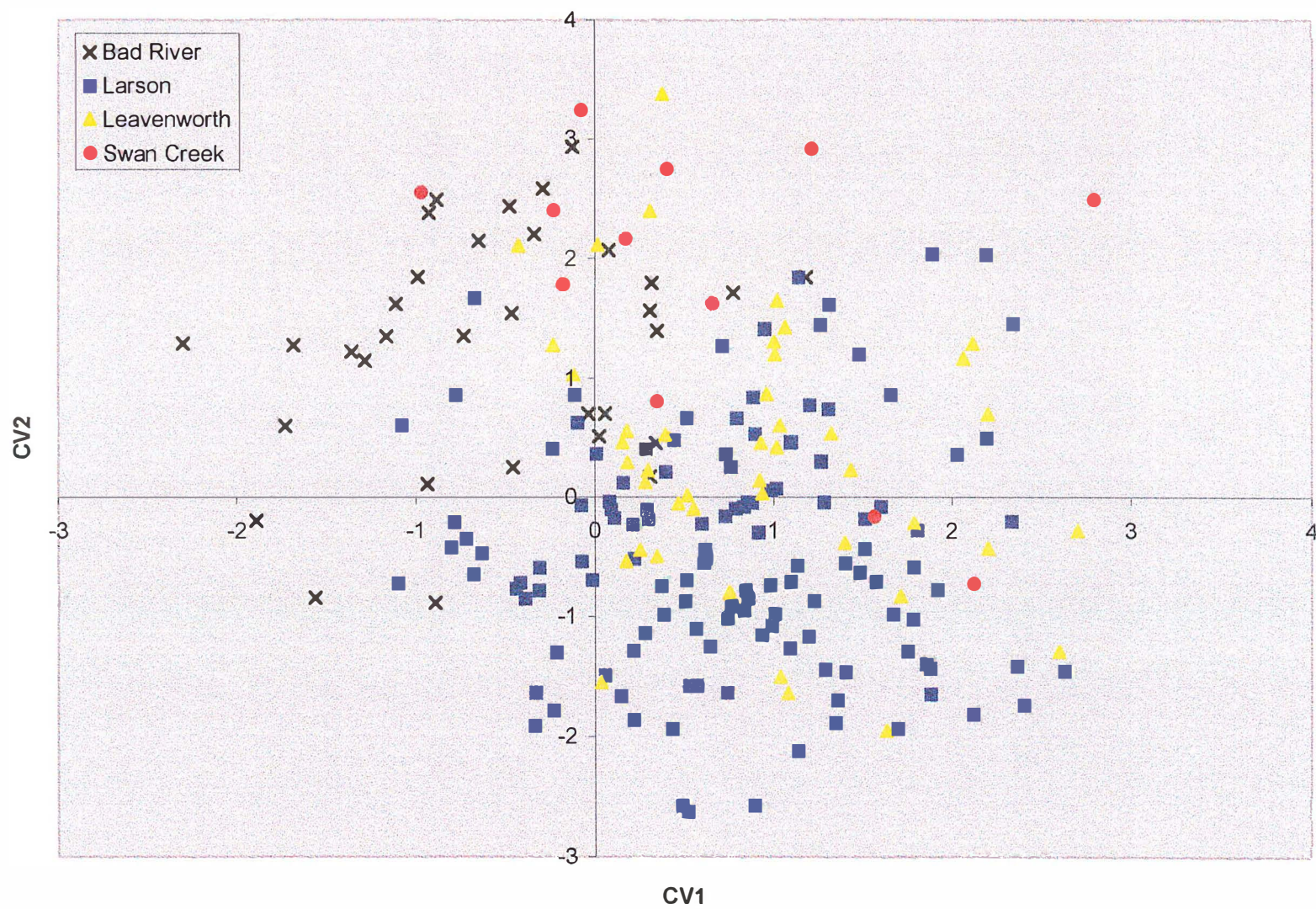


Figure 7.4. Canonical Plot of Bad River, Larson, Leavenworth and Swan Creek Components

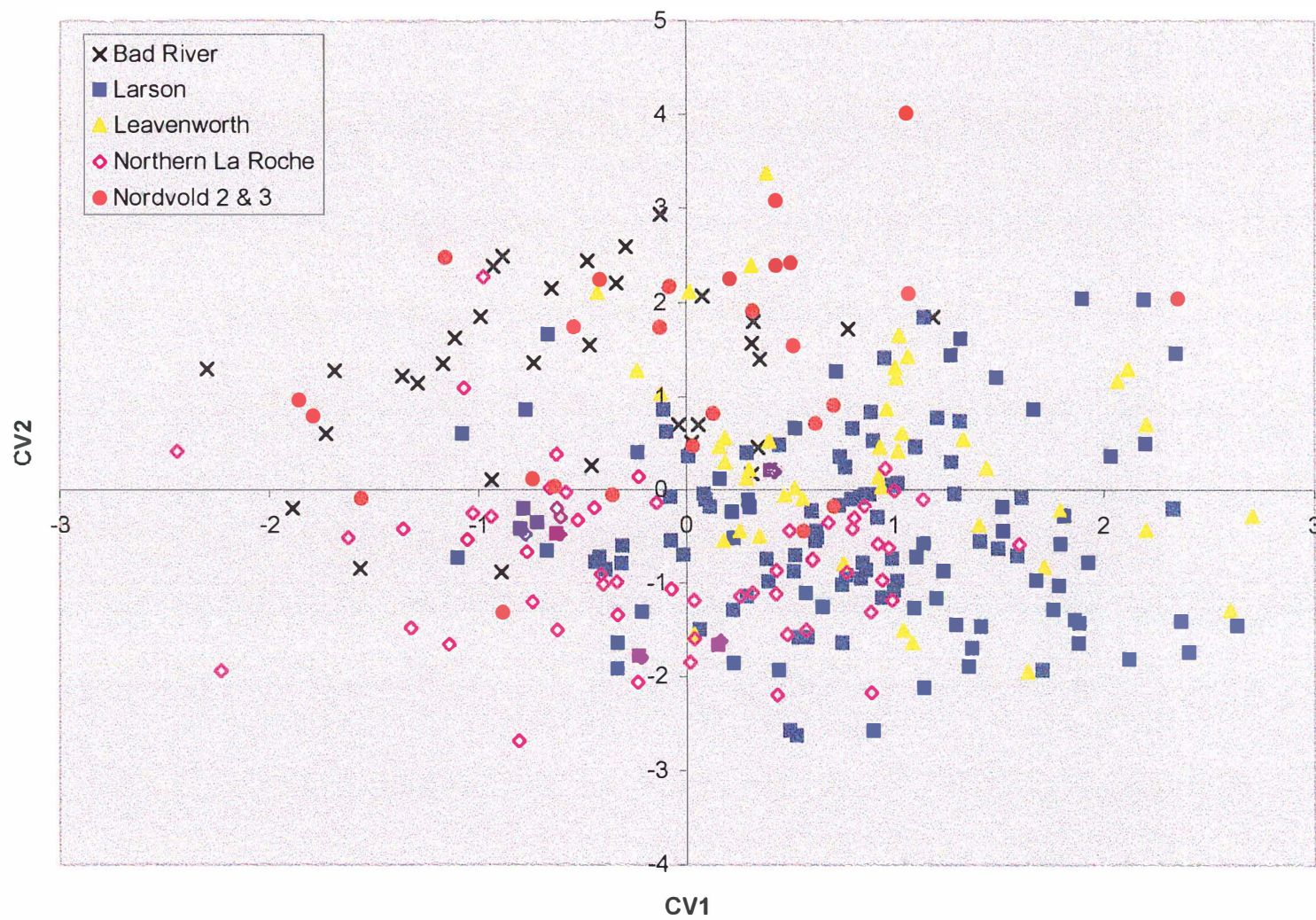


Figure 7.5. Canonical plot of Larson, Leavenworth, Bad River, Northern La Roche and Nordvold 2 & 3 components

presence of Akaska phase burials could also be considered as a possible explanation as Hurt (1957) originally suggested that some of the burials were associated with an earlier Akaska occupation. It does not necessarily follow that Akaska phase peoples would appear similar to Bad River phase peoples, especially when the temporal difference is taken into account. Unless many of the individuals currently ascribed to the Bad River phase are actually derived from Middle Missouri Tradition components and the similarity is due to the Terminal Middle Missouri influence on Akaska phase populations described by Johnson (1998). Nevertheless, I suggest that the similarity between the Sully components and the early Bad River sites argues against such a conclusion.

Nordvold 2&3 is more widely scattered with at least two individuals appearing in the Le Beau cluster and a few individuals falling in the Sully component cluster. If the temporal ascription of the site is correct as indicated by a lack of Euro-American trade goods (Wedel 1955), then perhaps Nordvold 2&3 represents an ancestral population for the later Bad River groups with some La Roche individuals present. It is also possible that the cemetery is associated with both village occupations, the early occupation corresponding to the individuals with La Roche affinities and the later occupation attributed to a Bad River phase population. In their description of the Bad River phase and associated sites, Hoffman and Brown (1967) conjectured that west (right) bank sites located outside the immediate Bad-Cheyenne region might also be Bad River phase sites and specifically mention the Nordvold villages as potential candidates for inclusion in the phase.

Morphological Patterns of Variation

The thin-plate spline transformation and Procrustes mean configuration overlay plots provide further insight into the morphological variation present between segments of the sample. In many cases, the conclusions of previous studies regarding the pattern of morphological change are supported. However, there are points of disagreement between this and previous studies.

Comparisons of configurations from Northern and Southern sites indicate that there is indeed a difference in cranial vault length between the two regions. The northern La Roche components, Mobridge F1/F3 and Rygh, are longer than their southern La Roche counterparts at Sully (burial areas A and D) and the Larson configuration is also longer than the Bad River mean. This indicates that the longer cranial vault of later periods was part of the genetic structure for the northern populations since at least the Extended Coalescent potentially arguing for continual Siouan gene flow at the northern aspect of the Arikara range. However, morphological dimensions such as cranial vault height and frontal curvature do not conform to expectations based on previous studies. The comparison of Sully A/D with the Early North sites illustrates the greater frontal curvature for the Sully mean. The location of midfrontal is as anterior on the Sully A/D mean as it is on the Larson configuration indicating that crania from these two earlier components have frontal curvature equal to that of crania from the later Larson. This seems to suggest that, unless there is evidence for Siouan admixture at Sully, the arched frontal of the later Le Beau sites could be attributed to the flow of Arikara genes from Sully instead of Siouan gene flow from the north.

While there are no statistically significant temporal trends in the truncated data set employed for the residual based analyses, the presence of such trends is hinted at by the canonical variates plot. Overall, the earliest components are towards the lower left corner with the latest components towards the upper right corner. Since the temporal variation is oriented in an oblique manner relative to both canonical variates, neither of them reflect the temporal information that is obviously present. Additionally, the thin-plate spline and Procrustes mean overlay plots depict variation that is patterned through time. Change in cranial vault length and facial height is immediately apparent from these plots; however, the landmarks that contribute the most to the changes in morphology, posterior occipital and prosthion, are not included in the statistical analyses based on the residuals from the Procrustes fitting. Prosthion was eliminated due to its tendency to be absent in older individuals. Posterior occipital was removed because it appeared to be expressing an alarmingly high degree of variation, which was feared to be related to the two different modes of observation. In retrospect, the inferior-superior variation in posterior occipital is probably to be expected since this a landmark where shape related sexual dimorphism is exhibited due to the nature of the muscle attachments in the region (Ahlstrom 1996). Eliminating midline landmarks such prosthion, which have a relatively higher frequency of absence, can not be remedied until efficient methods for coordinate estimation are developed. Fortunately, the use of consensus configurations for morphological analysis permits the retention of such landmarks.

The thin-plate spline and Procrustes consensus configuration overlay plots depict trends in both cranial vault length and facial height. The mean configurations from

earlier sites such as the Sully components, Mobridge Features 1 and 3, and Rygh uniformly exhibit shorter vaults and faces than the configurations from later sites such as Mobridge F2 and Larson. The greater length of the means from the Early North sites when compared to the Early South sites and the Larson mean when compared to the Bad River mean suggests that the difference is related to the genetic structure of the populations living in the Grand-Moreau region. Previous research (Jantz 1973) has contended that this change in cranial dimensions is due to gene flow from the Siouan speaking Mandan tribe to the north. The pattern of morphological change detected by this study does not negate such a hypothesis.

The supposed temporal trend in cranial vault height is not supported by this research. The Larson configuration exhibits one of the highest vaults in comparison to the other samples, and it is not until Leavenworth does there appear to be a noticeable decrease in cranial vault height. The decrease in overall height in the Leavenworth mean is related to a decrease in both upper vault height and cranial base height. This decrease in vault height may be related to an increase in admixture with the Mandan or Pawnee tribes. It has been demonstrated that both of these groups have lower cranial vaults than the protohistoric Arikara (Jantz 1977, Jantz and Willey 1981, Owsley et al. 1981) and interaction between the Arikara these tribes was documented historically including periods of time during which the Arikara residing in close proximity to each of these tribes (Trudeau 1914).

The small scale, localized variations between the components at the Mobridge site correspond with the temporal changes observed for the Northern sites. The average

cranium from the earlier Features 1 and 3 is shorter with less frontal curvature than the mean configuration from the ostensibly later Feature 2. The variation in morphology among the burial areas at Sully is also a matter of small scale, localized change. The Sully E configuration exhibits a taller but shorter vault with less curvature of the frontal when compared to the Sully A/D mean. This pattern of variation concurs with my earlier contention that most of the burials from Sully E can be attributed to the Initial and Extended Variants of the Coalescent, instead of the Post-Contact Variant. The pattern of variation for both of these sites agrees with previous research regarding the presence of temporal differences within these sites. For Mobridge the pattern of morphological change is congruent with observed patterns of temporal change in cranial morphology through time indicating that the temporal ordering of the Features proposed by Owsley and coworkers (1982) is correct. Based on the location of the Sully E individuals on the canonical variate plot and the overall morphological pattern for the mean configuration, burial area E appears to exhibit the earliest morphology with areas D and A representing slightly later occupations. This temporal ordering concurs with the female sequence detected by Owsley and Jantz (1978), but contradicts the male sequence in which area E is intermediate between A and D. Of course, it must be acknowledged that the morphological comparison presented here employs the mean configuration for a combined Sully A and D sample precluding the recognition of an intermediate position for Sully E. The merged A and D sample is justified by research into variability among the burial areas indicating that burial areas A and D are far more similar to one another than either is to area E (McKeown 1998, 1999).

Interpretations

The geographic patterns of morphological variation attest to gene flow among the populations that occupied these sites during the late prehistoric, protohistoric and historic periods. Based on ecological assessments of the Bad River site areas (Hoffman and Brown 1967, Lehmer and Jones 1968) and from ethnographic evidence (Trudeau 1914), it is clear that the populations that inhabited the villages on the right bank moved from area to area in search of resources such as timber for fuel and building purposes. This means that while these villages were permanent during their occupation, the inhabitants were abandoning villages and constructing new ones on a fairly regular basis. Such wholesale movement of people could potentially result in cemeteries associated with several different villages containing individuals that were members of the same subdivision of the larger population. This also means that reoccupation of a particular village would not necessarily be by the same subdivision of the population. These population based migrations would contribute to the patterns of variation observed, creating overall similarity among the individuals from these sites.

The effects of post-marital migration must also be considered since the movement of individuals between or within villages can produce different patterns of variation. According to Holder (1970), Arikara society was matrilocal with clan exogamy and village endogamy (Holder 1970). The presence of several bands in a village is supported by Parks (1979b) who suggests that each village might be composed of seven to ten bands. The proposed Arikara practice of clan exogamy and village endogamy would serve to maintain within village homogeneity especially as the adult males would

be more similar across clans within a village. However, variation between the villages would be much higher due to the lack of intervillage gene flow.

In contrast, Schneider and Blakeslee (1990) evaluated residence patterns among the Arikara based on enamel composition and determined that for Swan Creek, Mobridge and two other sites not considered here, and found a distinct pattern of greater male heterogeneity potentially indicating intervillage migration. This suggests that considerable village exogamy did occur among these populations. Such a pattern of marital migration would appear to agree with the striking degree of similarity among components such as Rygh and Mobridge F1 and F3 as well as previous findings of greater homogeneity across the earlier sites (Bass 1964, Jantz 1970). Additionally, Key and Jantz (1990) found that the Bad River sites taken together were only marginally more heterogeneous than Larson which suggests a pattern of intervillage migration for these Post-contact Variant sites. It should be noted here that a series of short term occupations at several sites in the same geographic area (such as the Bad-Cheyenne region) might also produce the homogeneity observed among the Bad River samples.

Raemsch (1998) estimated genetic variability for the males and females at the Larson site and determined that the cemetery samples exhibit relatively high within site variation with males being slightly more variable than the females. Under the social structure described by Holder (1970) this high degree of variability is not expected and may be a product of adult intervillage migration.

Based on analysis of ceramic styles at the multi-component Medicine Crow site, Deetz (1965) suggested that the traditional matrilineal social structure of the Arikara

weakened during the Post-contact Variant, most likely due to depopulation and contact with Euro-Americans. He suggested a shift towards a more patrilocal structure and greater interaction among the villages in an attempt to remain viable. Holder (1970) also described the general disintegration of traditional Plains Indian social structure as the authority of the chiefs was diminished. These shifts in the social structure could produce significant changes in the genetic variation exhibited by these populations.

Konigsberg (1988) has demonstrated that for fixed patterns of migration through time the more migratory sex will exhibit lower between-group variation and higher within-group variation than the less mobile sex. Further investigation of the patterns of male and female variability should help elucidate the contribution of marital migration patterns to the observed patterns of variation.

While the lack of comparative samples makes any statements about the effects of gene flow tenuous, the congruence in patterns of morphological change through time for this study and previous research suggests that previous hypotheses cannot be refuted. It is clear from the ethnographic accounts that due to depopulation, interaction with Euro-americans and pressures from other Native American tribes such as the Sioux, the traditional social fabric was rapidly unraveling (Trudeau 1914, Bradbury 1904, Brackenridge in Thwaites 1904, Chittenden 1935). In response to this social breakdown, the Arikara attempted to reinforce old alliances with the Pawnee and Mandan and even spent time in residence with both of these groups prior to their last move up to the Mandan village at Ft. Clark in 1836. The increasing interaction between these groups would explain higher levels of gene flow during this time.

The effects of depopulation due to disease cannot be discounted either. The Arikara experienced several epidemics of small pox during the 18th century and it is estimated that mortality may have been as high as 75% (Trimble 1989). Such a significant decrease in population numbers would have a considerable impact on the genetic variability present among the survivors. Village consolidation and greater interactions among villages would be likely responses to these drastic changes. Interestingly, it is suggested by ethnographic accounts (Tabeau in Abel 1939) that the inhabitants of the Leavenworth villages were the remnants of several surviving families. If this is literally true, it would have implications for genetic variability among the later sites. Perhaps investigating patterns of intrasite variation across the temporal span of these sites will identify changes in levels of within site variability.

Overall, the between sample variation for the groups included in this study indicates the presence of intervillage gene flow and large scale population movement. The patterns of morphological change through time seem to suggest that gene flow from neighboring tribes, particularly the Mandan, was a contributing factor. That the patterns of interaction among the bands and villages of the Arikara was impacted by the changing environment are more difficult to interpret from this research. However, further research employing sex as a variable may illuminate this question.

In conclusion, this study demonstrates the utility of investigating morphological variability via three dimensional coordinate data. By capturing shape information in the form of landmark coordinates interpretations of morphological variation are based on change in landmark location relative to all other landmarks. This

eliminates the need for a feature which is assumed to be constant across all individuals such as the transmeatal axis and the evaluation of multiple measurements in order to interpret variation in a morphological region. The landmark data more effectively depicts the patterns of morphological variation present which can be appreciated from graphic representations of the configurations. Changes in overall cranial dimensions can be assessed based on landmark positions and proportional change is more easily identified. Unexpected variation in a dimension not measured by the linear distances and angles can be lost in traditional analyses. With multidimensional data, variation in any direction accounted for by the coordinate data is present and incorporated in the analyses. More information about variability produces more powerful statistical evaluations.

This study would have benefitted greatly from the inclusion of comparative Mandan and Pawnee samples; however, Pawnee samples are no longer available and a Mandan sample would have been difficult to construct. The pictorial representations of morphological variation permit a more precise understanding of the exactly why change is occurring or variation is present. While cranial vault height appears to be changing through time, what specific morphological changes are driving the overall pattern of change need to be understood. This is not impossible to identify through other types of data; however, the landmark data provides a coherent picture from which such evaluations can easily be made. Noted in this study is a change in the proportion of the vault; namely, upper vault height and cranial base height. If change in morphology can be attributed to gene flow, then identifying a similar pattern in either the Mandan or the Pawnee could aid in interpretation. In general, morphological comparisons across

samples could have helped answer questions regarding gene flow between the Arikara and these other tribes with which they interacted.

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APPENDICES

Appendix A. Landmark Definitions

Alare (L/R): The most laterally positioned point on the anterior margin of the nasal aperture (Moore-Jansen et al. 1994:45 after Bass 1971 and Howells 1973).

Asterion (L/R): The common meeting point of the temporal, parietal and occipital bones, on either side (Howells 1973:166).

Basion: On the anterior border of the foramen magnum, in the midline, at the position pointed to by the apex of the triangular surface at the base of either condyle (Howells 1973:166).

Bregma: The posterior border of the frontal bone in the median plane. Normally this is the meeting point of the coronal and sagittal sutures (Howells 1973:167).

Dacryon (L/R): The apex of the lacrimal fossa, as it impinges on the frontal bone (Howells 1973:167).

Ectoconchion (L/R): The intersection of the most anterior surface of the lateral border of the orbit and a line bisecting the orbit along its long axis (Howells 1973:168).

Frontomolare Anterior (L/R): The most anterior point on the fronto-malar suture (Howells 1973:168).

Frontomolare temporale (L/R): The most laterally positioned point on the fronto-malar suture (Martin 1956:451).

Frontotemporale (L/R): A point located generally forward and inward on the superior temporal line directly above the zygomatic process of the frontal bone (Martin 1956:451).

Lambda: The apex of the occipital bone at its junction with the parietals, in the midline (Howells 1973: 168).

M1 (L/R): A point on the lateral maxillary alveolar crest just anterior to the first molar.

M2/M3 (L/R): A point on the lateral maxillary alveolar crest between the second and third molars.

Midfrontal: A point equidistant to both nasion and bregma along the surface of the frontal bone, in the midline.

Midparietal: A point equidistant to both bregma and lambda along the surface of the sagittal suture.

Nasion: The intersection of the fronto-nasal suture and the median plane (Howells 1973:169).

Opisthion: The inferior edge of the posterior border of the foramen magnum in the midline (Howells 1973:169).

Posterior Occipital: The most posterior point along the curve of the occipital bone.

Prosthion: The most anteriorly prominent, in the midline, on the alveolar bone, above the septum between the central incisors (Howells 1973:169).

Subspinale: The deepest point seen in the profile below the anterior nasal spine (Howells 1973:170).

Zygomatic Root (auriculare) (L/R): A point on the lateral aspect of the root of the zygomatic process at the deepest incurvature (Moore-Jansen et al. 1994:45).

Zygomaxillare Anterior (L/R): The intersection of the zygomaxillary suture and the limit of the attachment of the masseter muscle, of the facial surface (Howells 1973:170).

Zygoorbitale (L/R): The intersection of the orbital margin and the zygomaxillary suture (Howells 1973:170).

Appendix B. Eigenvectors for Principal Components 1 - 39

	PC1	PC2	PC3	PC4	PC5	PC6	PC7
X2	-0.021441	0.135631	-0.058693	-0.226685	0.054638	0.088197	-0.02444
Y2	0.184237	-0.033984	0.119966	-0.103492	0.107557	-0.07837	0.079075
Z2	-0.012373	0.005314	-0.012111	-0.000315	0.007248	0.002774	0.012522
X3	-0.033526	-0.009981	0.118798	-0.019219	0.056115	-0.001377	-0.054445
Y3	0.009806	0.101025	-0.059247	0.096427	0.028744	0.035587	0.057537
Z3	-0.000726	-0.005254	-0.010232	0.009621	0.000229	-0.008534	0.000129
X4	-0.025821	-0.047493	0.09653	-0.025679	0.08621	-0.033679	0.011989
Y4	0.003433	0.105128	-0.034084	0.05352	0.034407	0.036403	0.055094
Z4	0.040039	-0.002065	-0.033607	0.046064	0.031365	-0.063025	-0.012037
X5	0.016828	0.041397	0.034855	0.050114	-0.047231	-0.133608	-0.024778
Y5	-0.05197	0.078081	-0.022068	0.057691	-0.066919	0.095271	0.110848
Z5	-0.012259	-0.100729	-0.130011	0.088626	0.101565	-0.057614	0.003671
X6	-0.033011	0.020919	0.059266	0.069494	-0.001185	-0.074688	0.056579
Y6	-0.027923	0.147769	-0.043723	0.063537	-0.153993	0.063239	0.007886
Z6	-0.007427	-0.093654	-0.105685	0.108824	0.086135	-0.049715	0.01614
X7	-0.031485	0.013678	0.053876	0.02779	-0.027263	-0.1014	0.029819
Y7	-0.00782	0.046605	0.010161	-0.012293	-0.038329	0.017956	0.075107
Z7	-0.002356	-0.097465	-0.098094	0.074587	0.112463	-0.027422	-0.023738
X8	-0.042627	0.004479	0.015682	-0.001201	0.041663	-0.045094	-0.036675
Y8	0.059217	0.01258	0.069881	-0.039289	0.047412	0.006774	0.114067
Z8	0.002838	-0.063803	-0.098628	0.113306	0.169401	-0.101893	-0.10157
X9	-0.03574	0.014576	-0.130045	-0.03444	-0.002276	-0.047237	0.055052
Y9	0.120903	-0.080174	0.14499	-0.025692	0.032593	-0.01829	0.086861
Z9	0.068132	-0.102936	-0.138768	0.011164	0.067633	0.000421	-0.069982
X10	-0.006204	-0.010378	0.096361	-0.00572	0.073075	-0.059493	-0.003177
Y10	0.000237	0.109151	-0.042077	0.028937	0.02876	0.040799	0.051245
Z10	-0.021471	0.01304	0.022429	-0.023703	-0.042352	0.078811	0.019824
X11	0.030595	0.076003	0.059944	0.0431	-0.031904	-0.116636	-0.022594
Y11	-0.058156	0.083238	-0.049999	0.02737	-0.100665	0.082308	0.1061
Z11	-0.004649	0.084604	0.11406	-0.086929	-0.098293	0.053095	0.004909
X12	-0.028667	0.036966	0.061235	0.067615	0.009621	-0.078967	0.040969
Y12	-0.025869	0.166803	-0.066494	0.057196	-0.205244	0.059603	0.004884
Z12	0.018779	0.083598	0.120477	-0.101507	-0.08078	0.045589	-0.005829
X13	-0.033491	0.015385	0.041025	0.040627	-0.038787	-0.103563	0.045435
Y13	-0.005942	0.067336	-0.000269	-0.037802	-0.072877	0.024403	0.087744
Z13	-0.003302	0.082066	0.087295	-0.071816	-0.081759	0.028373	0.037504
X14	-0.049266	0.014393	0.014633	-0.012262	0.041077	-0.061283	-0.037887
Y14	0.060778	0.028745	0.049362	-0.054451	0.022602	0.03525	0.11725
Z14	0.011039	0.048765	0.104594	-0.091566	-0.145356	0.14014	0.08524
X15	-0.024097	0.046761	-0.107895	-0.045983	-0.011755	-0.051874	0.043941
Y15	0.117592	-0.057002	0.097885	-0.051365	0.005055	0.018288	0.073945
Z15	-0.075522	0.075225	0.155703	-0.000779	-0.064042	0.002994	0.087188
X16	-0.06856	0.0196	-0.033512	-0.241475	0.065456	0.144716	0.064529
Y16	0.14004	0.017963	0.084919	-0.07522	0.086864	-0.09381	0.047575
Z16	0.010873	-0.046122	-0.006907	0.024051	0.036457	-0.00816	-0.012712
X17	-0.055146	0.029977	-0.030056	-0.254917	0.035707	0.12075	0.044827

	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Y17	0.133173	0.022354	0.083151	-0.067941	0.105729	-0.090391	0.066421
Z17	-0.014461	0.030674	0.001498	0.007826	-0.016809	0.015927	0.006385
X22	0.254911	-0.034763	-0.032632	-0.049612	0.086474	-0.088351	-0.180074
Y22	-0.083766	0.104501	0.113224	0.215236	0.051942	-0.033272	-0.168559
Z22	0.014953	0.012898	0.017286	0.016017	-0.000371	-0.007196	-0.040008
X23	-0.09442	-0.107754	0.249866	0.25799	-0.032007	-0.121937	0.213798
Y23	-0.073673	0.152959	0.039699	0.140069	-0.158227	0.056637	0.026548
Z23	-0.103686	-0.116641	-0.040337	0.170654	0.085796	-0.062527	0.068735
X24	-0.068563	-0.090731	0.258535	0.276398	-0.067089	-0.132612	0.188949
Y24	-0.053722	0.168702	0.013246	0.123227	-0.194601	0.017112	0.017581
Z24	0.113747	0.124321	0.072217	-0.16966	-0.070337	0.064732	-0.065915
X25	0.303882	-0.009409	-0.162769	-0.09414	0.024079	0.017216	0.005712
Y25	0.194982	0.058266	0.085527	0.213903	0.131699	-0.118012	-0.464081
Z25	0.001911	0.021252	0.032601	-0.00314	0.013701	0.009501	0.008509
X26	0.118439	-0.171038	0.084246	0.272048	0.124495	0.355361	0.096289
Y26	-0.080279	-0.008988	-0.047222	0.0688	0.089741	0.371196	-0.035703
Z26	-0.15198	-0.004145	-0.146156	0.04803	-0.174833	-0.233455	0.050896
X29	-0.027522	-0.154633	-0.054543	0.048957	-0.098942	-0.014718	0.082783
Y29	-0.285507	-0.256508	0.052544	-0.183801	0.104602	-0.056324	-0.041094
Z29	-0.028617	-0.063824	-0.206816	0.078823	-0.071434	-0.003175	0.035083
X30	-0.050595	-0.008661	-0.011772	0.057241	-0.3105	0.072349	-0.325847
Y30	-0.185899	-0.076513	-0.074142	-0.034648	0.124585	-0.008071	-0.148431
Z30	-0.149587	-0.165591	-0.084773	-0.018067	0.015335	0.063874	-0.052279
X31	-0.118484	0.481803	-0.256035	0.161884	0.406851	-0.169774	0.012099
Y31	0.198542	-0.215121	-0.377473	0.032122	-0.241416	-0.072629	0.182164
Z31	-0.021855	-0.000727	0.001384	-0.011169	-0.034709	0.045675	0.011703
X32	0.133215	0.083048	-0.290046	-0.059677	-0.003438	0.01242	0.213451
Y32	0.306293	-0.249174	-0.105797	0.020234	-0.128829	-0.05606	-0.187591
Z32	0.006408	0.043269	0.01889	-0.006807	0.012659	-0.03351	-0.021217
X33	-0.084546	-0.0134	0.021281	0.060615	-0.304363	0.099611	-0.379822
Y33	-0.209671	-0.062008	-0.043222	-0.037972	0.095269	0.044693	-0.116552
Z33	0.145008	0.197592	0.022046	-0.030341	-0.07574	-0.091506	0.033222
X34	-0.026509	-0.135609	-0.016034	0.030281	-0.068521	-0.001756	0.091661
Y34	-0.273907	-0.256526	0.061106	-0.252949	0.084199	-0.092491	-0.017974
Z34	0.021502	0.082415	0.201957	-0.105507	0.062476	0.005198	-0.038663
X37	0.103225	-0.109312	0.021436	0.268896	0.164166	0.371809	0.108503
Y37	-0.07342	0.043725	-0.116352	0.058939	0.060755	0.324793	-0.101475
Z37	0.145576	0.026401	0.138555	-0.057327	0.16827	0.226329	-0.061284
X38	0.201623	0.007564	0.12352	-0.079897	-0.015451	-0.082828	-0.056701
Y38	-0.155624	0.059472	-0.125655	-0.101632	0.024496	0.019383	-0.07152
Z38	-0.000576	-0.007967	-0.020279	0.001936	0.010553	-0.013073	0.015202

	PC8	PC9	PC10	PC11	PC12	PC13	PC14
X2	-0.044895	-0.11811	0.107736	-0.018067	-0.051866	-0.080959	0.18482
Y2	-0.089374	-0.025501	0.02156	-0.029584	0.129775	-0.035851	-0.032856
Z2	-0.009164	-0.013902	-0.009284	0.011594	0.028273	-0.012374	0.078441
X3	0.059178	-0.008429	0.013653	0.067327	0.040288	-0.027098	0.178394
Y3	-0.136992	0.115745	0.000989	0.140696	-0.020116	-0.103112	-0.019751
Z3	-0.001655	0.009756	-0.000097	0.004079	-0.017595	-0.003833	0.022023
X4	0.036858	0.012115	0.036274	0.065835	-0.007671	-0.043062	0.106073
Y4	-0.167632	0.110591	-0.019161	0.099043	-0.032327	-0.061815	0.007498
Z4	-0.048015	-0.02336	-0.00036	0.00843	-0.026257	-0.024776	0.020259
X5	-0.058754	0.009177	0.015465	-0.028167	0.08314	0.202469	-0.001857
Y5	0.123337	0.015202	-0.079829	0.12234	0.006669	-0.130715	0.024706
Z5	-0.066177	0.083362	0.085105	0.05988	-0.133978	0.022721	-0.031607
X6	-0.064769	-0.043684	-0.005426	0.042578	0.060163	0.087769	-0.029849
Y6	0.112779	0.019199	-0.071115	0.074042	-0.008418	-0.044784	0.035018
Z6	-0.085827	0.032641	0.052906	0.052646	-0.095881	0.054738	0.021568
X7	0.04638	0.070086	-0.060722	0.047165	0.029497	0.122545	-0.111753
Y7	0.069211	0.008199	-0.070979	0.06579	0.038691	-0.013793	0.0678
Z7	-0.050919	0.054423	0.021281	0.064546	-0.10201	0.012128	0.047612
X8	0.012091	0.019145	-0.145341	0.038114	-0.040963	0.078868	0.036127
Y8	-0.066352	0.031461	0.096833	0.120079	0.019581	-0.027783	0.031831
Z8	-0.010294	-0.009797	-0.492303	0.06273	-0.080089	0.010497	0.039811
X9	-0.073381	0.133153	0.070012	-0.057645	0.041493	0.004943	-0.236338
Y9	0.015558	-0.203755	0.014968	0.190273	-0.140423	0.254086	0.242048
Z9	0.042796	-0.156102	-0.18418	-0.137926	0.292578	-0.242861	0.027395
X10	0.030762	0.008264	0.002166	0.118662	0.003767	0.011072	0.130832
Y10	-0.134669	0.106434	-0.005519	0.108203	-0.064384	-0.07598	-0.026185
Z10	0.05474	0.027373	-0.012789	-0.004991	-0.007289	-0.007347	0.027556
X11	-0.057578	-0.009631	-0.006184	-0.045044	0.106243	0.178992	0.063938
Y11	0.134834	0.01486	-0.054278	0.156205	-0.03813	-0.107149	-0.103881
Z11	0.071385	-0.055056	-0.058826	-0.046597	0.112581	-0.039684	0.05366
X12	-0.050834	-0.015316	-0.01733	-0.000615	0.055307	0.139509	-0.00766
Y12	0.1287	-0.009425	-0.072123	0.105991	-0.030107	0.000864	-0.080591
Z12	0.080475	-0.015329	-0.04821	-0.044396	0.069966	-0.084058	0.009684
X13	0.060869	0.063374	-0.075514	0.015159	0.028506	0.170615	-0.088054
Y13	0.078296	-0.006341	-0.022906	0.083607	0.029313	-0.013893	-0.016241
Z13	0.056223	-0.018996	-0.011938	-0.073557	0.081165	-0.053359	0.008589
X14	0.011558	0.001337	-0.152472	0.056093	-0.042985	0.087066	0.050656
Y14	-0.080181	0.040327	0.13864	0.117677	0.012889	-0.024751	-0.058106
Z14	0.011976	0.058908	0.475452	-0.103605	0.054638	0.00234	-0.027685
X15	-0.077741	0.104201	0.008742	-0.047058	0.041949	0.089172	-0.228865
Y15	0.032255	-0.153092	0.052198	0.156977	-0.115713	0.219318	0.174729
Z15	-0.028553	0.168609	0.120873	0.179767	-0.305089	0.307809	-0.000347
X16	-0.044388	-0.065959	0.077087	0.008171	-0.096487	-0.192376	0.168186
Y16	-0.1284	0.031194	0.003791	0.038295	0.117866	0.030899	-0.028465
Z16	0.007679	-0.000412	-0.050487	0.02949	0.01454	-0.055133	0.049518
X17	-0.050001	-0.112326	0.068964	0.024922	-0.098196	-0.144239	0.155152

	PC8	PC9	PC10	PC11	PC12	PC13	PC14
Y17	-0.122812	0.054524	0.002347	0.042377	0.138742	-0.000712	-0.055843
Z17	-0.03206	0.004678	0.024168	-0.020988	0.032233	0.030139	0.0771
X22	0.23234	0.164428	0.083016	0.167196	0.199437	0.016503	-0.028848
Y22	-0.09441	0.15276	0.112547	-0.023227	-0.114787	-0.173385	0.026444
Z22	-0.030293	-0.035773	-0.034784	-0.083715	0.032639	0.031552	0.073638
X23	-0.004947	-0.049655	0.073895	-0.011447	0.267236	-0.174672	0.083134
Y23	0.134379	-0.007257	-0.077433	0.03906	-0.031486	-0.04461	-0.015493
Z23	-0.21989	0.039012	0.111311	-0.014768	-0.04059	-0.00577	0.096848
X24	0.008393	-0.021394	-0.022286	-0.119998	0.227519	-0.036364	0.091782
Y24	0.152714	-0.011066	-0.072452	0.053565	-0.076314	0.022019	-0.138409
Z24	0.188578	-0.047767	-0.113367	0.057762	0.026588	-0.016013	-0.07288
X25	0.063233	0.165691	0.002663	0.29957	0.19363	0.07555	0.016296
Y25	0.139762	0.078675	0.22747	-0.063401	-0.101978	-0.09994	-0.021816
Z25	-0.005152	-0.089391	-0.045063	-0.036744	0.055583	0.08996	0.068821
X26	0.143063	-0.052922	0.063994	0.064295	-0.128846	-0.148796	0.028557
Y26	-0.041695	0.169334	-0.045013	-0.208646	0.068571	0.212357	0.140515
Z26	0.004056	-0.028914	0.0794	0.017932	-0.033048	0.049615	0.029735
X29	-0.009557	-0.008368	-0.034578	0.047206	-0.155663	-0.071129	-0.132298
Y29	0.176044	0.225628	-0.144549	-0.037227	-0.063053	0.036294	0.168012
Z29	0.210582	0.052573	0.183584	-0.050174	0.143766	0.094717	0.112222
X30	-0.102113	-0.008796	-0.06139	0.158837	0.024713	0.069552	0.141896
Y30	-0.098229	-0.4401	0.062212	0.159504	0.000742	0.087966	-0.045948
Z30	0.167763	-0.057857	0.214828	0.210898	0.147092	0.056795	-0.269726
X31	0.267423	-0.118578	0.138565	-0.023902	-0.043633	-0.049802	0.127016
Y31	-0.017111	-0.145904	0.007001	-0.246061	-0.119301	-0.053761	0.078892
Z31	0.023388	0.019813	-0.033035	-0.046769	-0.019755	-0.002028	-0.046228
X32	-0.040055	0.053037	-0.07557	0.121083	0.126044	0.119476	0.119947
Y32	-0.008078	0.083867	0.064671	0.072837	-0.101753	-0.112443	0.01173
Z32	-0.02914	-0.013729	-0.007951	-0.034903	0.019356	0.05881	0.065676
X33	-0.168254	-0.045246	0.031682	0.100344	0.085986	-0.047435	0.190964
Y33	-0.11154	-0.354231	0.034176	0.123606	0.107499	0.028137	-0.330198
Z33	-0.156725	0.091583	-0.088387	-0.176741	-0.223093	-0.086337	0.056038
X34	-0.027063	0.004522	-0.02274	0.003259	-0.18028	-0.10624	-0.129216
Y34	0.29428	0.290639	-0.009659	-0.037173	-0.067849	-0.064143	-0.010508
Z34	-0.193147	0.012483	-0.120903	0.047445	-0.141254	-0.126586	-0.256774
X37	0.087873	-0.04325	-0.069808	0.003494	-0.066254	0.053662	-0.08084
Y37	-0.08245	0.119567	-0.005084	-0.23216	0.132516	0.337526	-0.033983
Z37	-0.068342	0.053101	-0.137358	-0.031894	0.086777	0.013962	-0.120082
X38	0.226716	-0.232273	0.033799	-0.388122	-0.237101	0.192249	-0.151405
Y38	-0.183946	0.151677	0.041762	-0.128624	0.101267	-0.057646	0.014737
Z38	0.001901	0.015724	0.03679	-0.003675	-0.019964	-0.007772	-0.098001

	PC15	PC16	PC17	PC18	PC19	PC20	PC21
X2	0.10175	-0.022633	-0.047212	-0.046387	-0.028549	-0.006684	0.084209
Y2	0.157863	-0.015394	-0.082555	-0.077188	0.098168	-0.088506	-0.113315
Z2	-0.032819	-0.011248	0.012228	-0.00969	0.084632	-0.048387	-0.010094
X3	-0.059105	-0.030776	0.052291	0.065358	-0.037348	-0.191369	0.060829
Y3	0.169243	0.050025	0.020028	0.008026	0.142861	0.045692	0.161416
Z3	0.023626	0.027238	0.006595	-0.033341	-0.017223	-0.025893	-0.01701
X4	-0.064709	-0.053403	0.044249	0.02596	-0.003342	-0.312463	-0.033697
Y4	0.120989	0.042944	0.080315	0.014787	0.136991	0.084269	0.15236
Z4	0.018984	0.030793	-0.004377	-0.069789	-0.045214	0.014485	-0.025393
X5	-0.065361	0.032727	-0.109015	0.073415	-0.068808	0.01942	0.235532
Y5	-0.094833	-0.054513	0.149827	-0.106432	0.065683	0.063	0.045047
Z5	0.007304	0.11613	0.037279	-0.053513	-0.081554	-0.029259	-0.111746
X6	-0.024212	-0.040465	-0.096745	-0.024202	0.04236	0.034873	0.188183
Y6	-0.087286	0.036929	0.154297	-0.110182	-0.015026	0.065542	0.053433
Z6	-0.012753	0.06521	0.032909	-0.055056	-0.037092	0.003418	-0.016032
X7	0.006483	0.096522	-0.12036	0.014504	-0.003126	0.061494	0.025622
Y7	-0.109494	0.002994	0.119602	-0.029784	0.035197	0.108787	0.091966
Z7	-0.023734	0.096775	0.105225	-0.068973	-0.031276	-0.031076	-0.124276
X8	0.086664	-0.076238	0.035754	-0.023601	0.019855	-0.12798	0.044736
Y8	-0.090042	0.143385	0.077345	0.007705	0.019789	0.099518	-0.038809
Z8	0.151015	-0.081852	-0.019778	0.022531	-0.11452	-0.095826	0.003583
X9	-0.00892	0.054015	-0.04371	-0.225004	-0.04892	-0.065347	-0.15913
Y9	-0.141921	0.053937	0.022086	0.028507	-0.149971	0.257752	-0.078357
Z9	-0.22826	0.072799	0.011888	0.03752	0.098586	0.091056	0.009719
X10	-0.105903	-0.050217	-0.003155	0.008724	0.015461	-0.254756	-0.025574
Y10	0.148127	0.062439	0.055009	0.04567	0.11552	0.052699	0.133392
Z10	0.035738	-0.038157	0.030882	-0.039863	0.021469	0.02	-0.014363
X11	-0.109991	0.052218	-0.101703	-0.068178	-0.009402	0.067479	0.209272
Y11	-0.066838	-0.040124	-0.039931	0.134876	0.083432	-0.128982	0.018344
Z11	0.011589	-0.118807	-0.006704	0.017706	0.023455	0.054845	0.074069
X12	-0.097554	-0.065796	-0.105489	-0.046306	0.047957	0.05576	0.202855
Y12	-0.055814	0.083235	-0.021092	0.107023	0.030685	-0.126502	-0.000586
Z12	0.050831	-0.07752	0.004019	-0.021065	-0.02189	0.046859	-0.008699
X13	-0.078799	0.024422	-0.196245	0.059158	0.07995	0.120164	0.008312
Y13	-0.090718	0.0321	-0.069515	0.149724	0.053418	-0.060879	0.086155
Z13	0.026511	-0.12701	-0.054451	-0.006802	0.012802	0.078165	0.07354
X14	0.030302	-0.093688	0.00656	-0.052438	0.08965	-0.08175	0.024506
Y14	-0.038893	0.154308	-0.021241	0.119857	0.052563	-0.041218	-0.027811
Z14	-0.201331	0.125746	0.070644	-0.095343	0.121686	0.030184	-0.032452
X15	-0.127631	0.023103	-0.096497	-0.225617	0.092391	-0.043637	-0.217992
Y15	-0.07001	0.119979	-0.161218	0.138864	-0.178818	0.010993	-0.014384
Z15	0.208473	-0.211256	0.044229	-0.174798	0.007186	-0.022964	-0.114607
X16	0.137052	-0.065043	-0.075937	0.066234	-0.08618	0.08974	-0.05418
Y16	0.132932	0.05231	0.012094	-0.130462	0.104056	-0.0614	0.038605
Z16	-0.062821	-0.010224	0.010263	-0.010751	0.008154	-0.019412	-0.036068
X17	0.156505	-0.073084	-0.088541	0.080217	-0.094776	0.148182	-0.085408

	PC15	PC16	PC17	PC18	PC19	PC20	PC21
Y17	0.118365	0.054462	-0.032265	-0.08347	0.121046	-0.141476	0.036409
Z17	0.025129	-0.025942	0.021865	-0.06537	0.111602	-0.039467	0.00481
X22	-0.059902	0.042532	0.184491	0.031506	-0.217982	-0.048507	-0.090173
Y22	0.07335	-0.088053	0.052708	0.109615	0.040068	0.054993	0.143034
Z22	-0.017404	-0.018453	0.029875	-0.058481	0.009259	0.036179	0.017449
X23	0.174528	-0.010902	0.154823	0.14505	-0.093587	0.029444	-0.164596
Y23	0.10684	0.001381	0.170799	-0.141868	-0.072095	0.05895	-0.099549
Z23	-0.027998	-0.03549	0.061779	0.110914	0.087596	0.089115	0.11768
X24	0.175546	0.123913	0.003694	0.093178	-0.030665	0.035012	-0.245176
Y24	0.148249	0.081571	-0.062586	0.063126	-0.059067	-0.060484	-0.157724
Z24	0.065402	0.004862	-0.028563	-0.140061	-0.121552	-0.009258	-0.09451
X25	-0.008405	0.034341	0.258745	0.106815	0.031703	0.043491	-0.040825
Y25	-0.038769	-0.126596	-0.071368	0.020932	0.000439	0.181993	-0.029129
Z25	-0.113661	-0.066476	0.040989	-0.092311	0.079089	-0.004822	0.083572
X26	-0.078187	0.117625	-0.09712	-0.178236	0.141839	-0.269998	0.082079
Y26	-0.119929	-0.248525	0.154974	0.091758	0.134402	-0.090776	-0.091373
Z26	-0.059208	-0.021693	0.1943	-0.018549	-0.141887	0.076754	0.086069
X29	-0.151354	-0.089535	0.113719	0.131643	-0.057345	0.191586	-0.079044
Y29	0.043982	0.176386	0.069232	-0.205949	0.212126	0.192521	-0.139457
Z29	0.163776	0.014471	-0.076678	-0.155184	-0.117858	-0.055779	0.124918
X30	0.009936	0.201977	-0.172545	0.015928	0.175923	0.052736	-0.114582
Y30	0.022912	0.080232	0.117842	0.057995	0.108923	-0.197689	-0.069488
Z30	0.252532	-0.148071	-0.201076	0.268974	-0.013722	-0.058488	0.126208
X31	-0.001078	0.124529	-0.106823	0.037697	0.11095	0.129611	-0.139253
Y31	0.150677	0.028007	-0.175362	-0.043252	0.067584	0.041946	-0.054959
Z31	-0.109663	-0.007224	-0.148623	0.001061	0.065121	-0.042942	0.03566
X32	0.117586	0.075466	0.171308	0.142079	0.140968	0.068698	0.083854
Y32	0.033887	-0.195729	-0.036969	0.048912	0.133025	0.071494	-0.01187
Z32	-0.120798	-0.006956	-0.053386	0.028883	0.129687	-0.023312	-0.020885
X33	0.15572	0.301988	0.071962	-0.076901	0.018674	-0.040033	0.046425
Y33	-0.057286	0.077174	0.156868	-0.116866	0.037187	0.099058	-0.015576
Z33	-0.121097	0.322935	-0.0668	0.232985	-0.094605	-0.254834	-0.080887
X34	-0.156714	-0.101297	0.103096	0.131412	-0.066076	0.005468	0.058503
Y34	0.005243	0.317248	-0.064658	0.181511	0.081221	0.018466	0.199809
Z34	-0.09594	0.065868	0.071687	0.112079	0.010514	0.140893	-0.075276
X37	0.039572	0.238219	-0.069736	-0.146961	-0.221993	0.123817	0.20774
Y37	0.045993	0.023203	0.041784	0.353955	-0.019815	0.037154	-0.235385
Z37	0.152229	0.111479	-0.106107	-0.017607	-0.08025	0.242093	0.025125
X38	0.238334	0.153668	0.438404	0.085694	0.168377	-0.073458	0.212001
Y38	-0.026831	0.053189	0.114131	-0.092865	-0.517943	-0.136823	0.204158
Z38	0.099382	0.059239	0.00683	0.054775	-0.059133	-0.057523	-0.028464

	PC22	PC23	PC24	PC25	PC26	PC27	PC28
X2	-0.073123	0.165616	-0.065658	-0.047949	0.021809	0.029173	-0.081284
Y2	-0.112306	0.126283	0.116948	-0.086626	0.151579	-0.190229	0.050224
Z2	0.038183	0.114706	-0.032169	0.074945	0.05208	0.017367	0.004766
X3	0.269656	-0.001917	0.062072	0.065235	-0.197343	-0.145495	0.041023
Y3	0.061795	-0.023745	0.057797	0.026416	-0.018589	0.045587	-0.064629
Z3	-0.052251	0.002355	0.046849	0.024364	-0.025512	-0.013985	-0.019557
X4	0.175878	-0.17716	0.051118	0.079253	-0.099617	-0.108202	0.120017
Y4	0.063284	0.02321	0.116585	0.029893	0.00003	-0.058298	-0.100582
Z4	-0.019038	-0.05789	0.03949	0.029633	-0.078065	0.020597	-0.043958
X5	0.015727	-0.07925	0.241153	0.077288	0.116945	-0.080722	-0.157464
Y5	-0.024682	-0.131228	-0.100714	0.022754	0.030706	0.032904	0.074235
Z5	-0.048974	-0.078697	0.134959	0.007049	-0.070913	0.016644	-0.053593
X6	-0.027021	-0.133446	0.132893	-0.060184	0.041598	0.038886	0.002208
Y6	-0.090605	0.001054	-0.042758	0.069801	0.045565	-0.088226	0.026685
Z6	-0.049063	-0.083226	0.039773	-0.006226	-0.066313	-0.028443	-0.044123
X7	-0.232944	0.031928	0.104069	-0.082015	-0.282991	-0.07424	0.143625
Y7	-0.012077	-0.141977	-0.020853	0.035228	0.062749	0.023497	-0.023045
Z7	0.060599	-0.070165	0.086027	-0.017341	-0.114782	0.03241	-0.05854
X8	-0.011519	-0.031499	-0.013368	0.021558	-0.049912	-0.06768	0.129014
Y8	0.108055	-0.123825	0.06484	0.07003	-0.022454	0.081702	0.007561
Z8	-0.001545	-0.046743	-0.024654	-0.037581	0.148206	0.090075	-0.063355
X9	0.023382	-0.200233	-0.095301	0.163895	0.186763	0.068229	0.037331
Y9	0.013961	-0.094223	0.024376	-0.106472	0.095622	0.196848	0.15171
Z9	0.027304	-0.029051	0.120123	-0.016733	-0.104493	0.059233	0.063471
X10	0.177728	-0.10458	0.042532	0.078558	-0.115259	-0.171169	0.066892
Y10	0.056091	0.078848	0.091154	0.008715	-0.058442	-0.047106	-0.121877
Z10	-0.090814	0.016553	0.031968	-0.005215	0.044041	-0.003744	-0.028815
X11	0.05728	0.012102	0.136506	0.026436	-0.004325	-0.0862	-0.122662
Y11	-0.074817	-0.124571	-0.163779	0.054258	0.076793	0.097735	-0.055819
Z11	-0.062982	-0.003364	-0.03182	0.023563	0.09304	-0.012159	0.053731
X12	-0.021929	-0.086523	0.121018	-0.071675	0.031133	0.123823	-0.162915
Y12	-0.093585	0.07063	-0.120869	0.063636	0.055615	-0.059864	0.056066
Z12	-0.048274	-0.000235	0.055377	0.055416	0.074417	-0.01719	0.065712
X13	-0.263143	0.061709	0.063312	-0.046874	-0.381307	0.036848	0.08527
Y13	-0.040214	-0.05057	-0.10716	0.086682	0.089224	0.034194	-0.032782
Z13	-0.115998	-0.00658	0.002678	-0.005056	0.114661	0.017295	0.070679
X14	-0.018242	0.016477	-0.060811	0.007491	-0.092028	-0.040433	0.049157
Y14	0.12374	-0.070081	0.053037	0.114464	0.001757	0.070964	-0.036718
Z14	-0.02679	0.00771	0.074497	0.078046	-0.119185	-0.024926	0.038568
X15	0.02582	-0.02083	-0.139766	0.105354	0.069731	0.11624	-0.006608
Y15	0.074768	-0.013775	-0.067792	0.13633	0.125504	0.165168	0.005115
Z15	0.016064	0.074961	-0.090447	-0.147782	0.100056	0.02415	0.01017
X16	-0.023729	-0.068678	0.039854	-0.076923	-0.032188	-0.123274	-0.031935
Y16	-0.030439	0.095108	0.067938	-0.088771	0.078475	-0.071187	0.171167
Z16	0.07595	0.0118	-0.008487	0.057278	-0.04155	0.037019	-0.050979
X17	-0.05324	0.012393	-0.035726	-0.091704	-0.200483	-0.057558	-0.138638

	PC22	PC23	PC24	PC25	PC26	PC27	PC28
Y17	0.046631	0.130117	0.074498	-0.028365	0.126481	-0.086751	0.199809
Z17	-0.042024	0.105088	-0.013051	0.082731	0.085885	0.027948	0.029223
X22	0.01401	0.133001	-0.044214	-0.065086	0.013758	-0.09831	-0.13033
Y22	0.192581	-0.019689	-0.075982	0.109712	-0.152478	0.070427	0.157626
Z22	-0.054632	-0.023462	-0.005529	0.02664	0.024189	-0.033726	-0.130115
X23	-0.08143	-0.035237	-0.050126	-0.006551	0.063838	0.040962	0.159785
Y23	0.048996	-0.064397	0.206851	0.045555	-0.119866	0.065379	0.002593
Z23	-0.193948	-0.024622	-0.197775	0.016648	0.017206	-0.033788	0.092567
X24	0.051702	0.133365	-0.109124	-0.074109	-0.026883	0.113852	-0.262663
Y24	0.109256	0.041346	0.126603	-0.044129	-0.173976	0.057898	-0.074374
Z24	0.045827	-0.068138	0.273887	0.011445	-0.038481	-0.056241	-0.03509
X25	-0.146935	0.0629	-0.081501	-0.124332	-0.03896	-0.022647	-0.070646
Y25	-0.027514	-0.023897	-0.113505	0.087294	0.131842	0.010154	-0.047452
Z25	0.028024	0.073798	-0.063661	0.079015	-0.139907	0.058269	-0.18629
X26	-0.217586	0.131118	0.154723	-0.198218	0.002975	0.17351	-0.16943
Y26	-0.034559	-0.127244	0.165773	-0.189845	0.067203	0.048909	0.186049
Z26	-0.104775	0.00056	-0.075475	-0.076411	-0.014235	-0.404145	-0.017156
X29	0.09892	0.341383	0.27904	0.089902	0.220097	-0.045142	0.134891
Y29	-0.032032	0.142193	0.035341	0.318325	-0.013707	-0.014339	-0.129755
Z29	0.150014	-0.062876	-0.000224	-0.071091	0.058474	0.059662	0.162824
X30	0.120016	0.239784	-0.012994	-0.07655	-0.061186	0.058306	0.366662
Y30	-0.280675	0.064642	0.044781	0.329362	0.035311	0.00815	0.053843
Z30	0.005272	0.037231	0.059484	0.159273	-0.023563	0.037911	-0.056225
X31	0.000363	0.078398	0.156109	-0.099571	0.136591	0.011286	0.119923
Y31	0.150978	-0.127097	0.033178	0.026932	-0.040032	-0.08735	0.048596
Z31	0.275086	0.204177	-0.189894	-0.162973	0.056895	0.00555	-0.123837
X32	0.129159	0.056761	-0.064964	0.061437	-0.032843	0.172451	0.040751
Y32	-0.122708	-0.06298	0.013527	-0.046572	-0.125988	0.114414	0.048813
Z32	0.175963	0.23192	-0.184537	-0.04542	-0.036551	-0.051233	-0.195967
X33	-0.05142	-0.173638	0.100182	-0.075762	0.25777	-0.049543	-0.174138
Y33	0.234004	-0.060362	-0.134103	-0.403452	-0.04952	0.006455	0.028037
Z33	-0.145422	-0.020597	-0.075719	-0.036815	0.032166	-0.046498	0.059482
X34	0.130822	0.239546	0.287521	0.025665	0.206132	-0.033919	-0.005185
Y34	0.00611	-0.126659	-0.013137	-0.265463	0.153087	0.025571	0.087247
Z34	-0.023831	-0.104313	0.011957	-0.094416	-0.039905	-0.044453	-0.014812
X37	0.00371	0.100923	-0.218563	0.098489	-0.017681	-0.399287	0.142028
Y37	0.001458	-0.039878	0.065755	0.020592	0.02673	-0.16934	-0.134845
Z37	0.104742	-0.093729	-0.047498	0.248091	-0.012341	0.091537	0.135889
X38	0.041207	0.025235	-0.036048	0.025481	-0.068279	0.139786	0.028978
Y38	-0.092135	0.278479	0.026843	0.010382	-0.116597	0.384454	0.103686
Z38	0.002115	-0.123017	0.040831	-0.082688	0.055835	0.035991	0.002535

	PC29	PC30	PC31	PC32	PC33	PC34	PC35
X2	-0.055444	0.023768	0.113276	-0.120387	-0.221416	-0.077722	-0.120058
Y2	0.027642	-0.085532	-0.021286	-0.019246	0.074238	0.0814	0.13795
Z2	0.014443	0.010602	0.077757	-0.02298	0.147539	-0.07052	-0.024614
X3	-0.023775	-0.028767	-0.005609	0.197586	-0.130401	0.074622	0.131469
Y3	-0.001335	0.136428	0.151729	-0.085594	-0.038064	-0.135922	0.008839
Z3	0.007026	-0.016875	-0.061239	-0.027269	-0.038676	-0.015945	0.00089
X4	0.005953	0.060888	0.05347	-0.074884	-0.044447	0.150905	-0.052306
Y4	-0.016261	0.209243	0.131037	0.035373	0.038665	-0.088029	-0.064727
Z4	-0.041935	-0.038946	0.020472	0.108557	-0.060276	0.043227	0.067887
X5	-0.046623	-0.218482	0.103572	0.152398	-0.02591	0.110366	-0.295091
Y5	-0.006184	0.126613	-0.058498	-0.040499	0.096976	0.004915	0.168242
Z5	-0.001426	-0.073254	-0.006741	-0.090592	0.050145	-0.050457	-0.045424
X6	-0.087733	-0.177444	-0.070081	-0.014555	0.022744	-0.009525	0.0649
Y6	-0.018926	-0.03138	-0.030337	-0.043841	0.020812	0.032924	-0.04926
Z6	-0.015683	-0.092763	-0.012847	-0.029084	-0.000132	0.027177	-0.014604
X7	0.370514	0.069082	-0.099188	0.139961	0.010971	0.011388	-0.177924
Y7	-0.032255	0.113008	0.018669	0.133605	0.129855	0.123295	-0.039988
Z7	-0.048339	-0.024397	-0.026959	-0.072888	0.063567	-0.023672	-0.004057
X8	-0.026726	0.043683	-0.042413	-0.109321	-0.090603	0.122022	-0.069458
Y8	0.003378	0.197818	-0.029302	-0.011098	0.145797	0.051942	-0.111628
Z8	-0.02281	0.057675	0.026351	0.127402	0.149587	-0.020063	-0.041656
X9	-0.011026	0.143142	0.021276	0.118665	-0.013573	0.066718	-0.051716
Y9	-0.032006	0.19005	0.054901	-0.039709	-0.161051	-0.198661	0.005294
Z9	-0.023149	0.054527	0.06175	-0.013667	-0.043147	-0.132064	-0.166398
X10	0.103558	0.106865	0.111854	-0.059533	-0.045488	0.12296	0.027052
Y10	-0.000795	0.141212	0.114034	-0.043089	0.003064	-0.12178	-0.028849
Z10	0.08633	0.021541	-0.0942	-0.118914	-0.06885	-0.035568	-0.014637
X11	-0.13534	-0.064539	0.052197	0.049535	0.095867	-0.005075	0.054774
Y11	0.069928	-0.021471	0.094067	-0.021727	0.045587	0.00554	0.087938
Z11	0.000654	0.109444	-0.021047	0.047691	-0.138291	0.042358	-0.028976
X12	-0.181415	-0.053474	-0.011813	-0.02136	0.103624	-0.001118	0.196624
Y12	0.064086	-0.126013	0.0727	-0.055946	-0.06673	-0.013828	-0.01908
Z12	-0.008901	0.093471	-0.040392	-0.009604	-0.093981	0.000567	-0.013603
X13	0.279999	0.08793	0.107041	0.086895	0.048913	-0.021469	0.122416
Y13	0.078427	-0.005427	0.06037	0.052975	0.147209	0.083513	-0.018282
Z13	0.019667	0.099198	0.000945	0.076033	-0.119539	-0.003643	0.040299
X14	-0.032302	0.08642	0.012475	-0.15092	-0.090755	0.054662	0.082124
Y14	0.090594	0.102266	-0.015066	-0.000955	0.247375	0.069268	-0.146207
Z14	-0.089364	-0.077655	-0.076399	-0.052953	-0.063905	0.002967	0.005228
X15	-0.07393	0.091358	0.012411	0.212845	0.062776	-0.047231	0.014763
Y15	0.184376	-0.000988	0.085453	-0.227846	0.029072	-0.119471	0.058634
Z15	0.000095	-0.049964	-0.121496	0.184169	0.011704	0.03413	-0.008071
X16	-0.029528	-0.021985	0.068294	0.18792	0.260354	0.038703	0.027178
Y16	-0.023205	0.061638	-0.004844	-0.099655	0.003517	-0.081941	0.019741
Z16	-0.004728	-0.034137	-0.038597	0.097806	0.070313	0.094956	-0.040997
X17	-0.018397	-0.057671	0.04255	0.2142	0.190023	0.095434	-0.058394

	PC29	PC30	PC31	PC32	PC33	PC34	PC35
Y17	0.016928	0.020288	0.038974	-0.114235	0.086268	-0.104212	0.081249
Z17	0.032858	0.008541	0.085215	-0.101445	0.068576	-0.176549	-0.032537
X22	0.08727	0.105654	-0.109997	0.290357	-0.02262	-0.297169	0.065485
Y22	0.07656	-0.028873	-0.207287	0.180485	-0.153763	-0.242282	0.056332
Z22	-0.077323	0.092009	-0.031443	0.015257	0.011852	0.054584	0.080549
X23	0.058644	-0.287616	0.207915	0.039223	0.215729	-0.116143	0.169936
Y23	-0.09289	-0.209421	0.018844	-0.132598	0.116001	-0.132349	0.084466
Z23	0.022504	-0.013984	-0.022306	0.068948	-0.088166	0.038035	-0.00395
X24	-0.127833	0.266688	-0.214848	-0.070231	-0.10699	0.200818	-0.218594
Y24	-0.171006	-0.044064	-0.018784	-0.096622	-0.019123	-0.114137	-0.095976
Z24	-0.023016	-0.041181	-0.073338	-0.041935	0.014404	-0.083982	-0.014387
X25	-0.10275	-0.08579	0.046773	-0.028348	0.027131	0.088159	-0.004242
Y25	-0.030728	-0.049519	0.245198	-0.029055	0.04389	-0.038124	-0.050282
Z25	-0.02449	0.174455	-0.121912	0.025828	0.167088	-0.009579	0.42958
X26	-0.034567	0.009603	0.123295	0.190422	-0.175102	0.052033	0.054545
Y26	0.108745	-0.009657	-0.05871	-0.043659	0.212653	-0.157486	-0.264715
Z26	-0.091943	0.112646	0.039947	-0.126567	0.033746	-0.003349	-0.047004
X29	0.017072	0.055444	0.090691	0.10621	-0.058202	0.144503	-0.037465
Y29	0.14518	-0.13778	0.253092	-0.082082	-0.075292	0.042515	0.052622
Z29	0.051923	0.055651	0.121936	0.072313	0.038133	0.112903	0.079368
X30	-0.310523	0.100344	0.128922	0.170055	0.154094	0.109378	0.021826
Y30	-0.159814	-0.037226	-0.256313	0.111485	0.050279	-0.167395	-0.073069
Z30	-0.027487	0.136792	0.003499	-0.115095	0.053654	-0.025877	0.018562
X31	0.091311	0.062709	-0.167534	-0.072189	0.047408	0.208477	0.087956
Y31	0.102029	0.073511	-0.073664	0.042795	-0.039203	-0.254774	0.116424
Z31	0.134995	-0.154281	-0.047192	-0.122379	0.102489	-0.047218	-0.148477
X32	0.006824	-0.297433	-0.116578	0.124557	-0.259057	0.100459	0.001247
Y32	-0.052389	-0.022413	-0.173622	-0.299458	0.108466	0.305501	0.042228
Z32	0.152583	-0.068932	-0.141128	-0.074265	0.168453	-0.092758	-0.016634
X33	0.41333	0.036281	-0.185508	0.002362	0.006801	0.092351	0.07735
Y33	0.123189	-0.120887	0.16628	-0.031265	-0.099937	0.089919	0.074539
Z33	-0.074725	-0.094754	0.05754	0.015323	-0.014417	0.016196	0.124594
X34	0.135227	0.002701	-0.170825	0.037347	0.017738	0.100996	0.204409
Y34	-0.246978	-0.004665	-0.215667	-0.013171	0.025384	-0.146079	0.056421
Z34	-0.005928	0.070078	-0.014874	-0.086147	-0.036681	-0.030907	0.084141
X37	-0.071566	0.028583	-0.082453	-0.056661	0.132244	0.027868	-0.054056
Y37	-0.084155	0.113641	0.114619	-0.055112	-0.116451	0.039435	0.302091
Z37	0.044622	-0.170669	-0.173956	-0.001832	-0.055037	0.159924	0.06144
X38	0.052936	0.086877	0.111208	0.087495	0.179953	0.106619	-0.051508
Y38	0.041297	0.080094	0.022276	-0.139669	0.100776	0.08358	0.053136
Z38	0.068934	0.097195	0.23509	0.053743	-0.145544	0.072072	0.026848

	PC36	PC37	PC38	PC39
X2	-0.204018	0.231968	-0.199218	0.173119
Y2	0.04353	0.108279	0.079791	-0.251173
Z2	0.018392	0.003022	0.042173	-0.126586
X3	-0.04907	-0.067091	0.038653	-0.075752
Y3	-0.064806	-0.016152	0.118253	-0.053073
Z3	0.005793	-0.004321	0.009988	-0.060416
X4	0.007984	0.219103	0.047545	-0.033825
Y4	0.049194	-0.135895	0.074411	0.027477
Z4	0.000316	0.079025	-0.025362	0.031194
X5	-0.115376	-0.123194	-0.051901	0.095719
Y5	0.012901	0.136881	0.134642	-0.197171
Z5	0.032987	0.015498	0.024734	-0.028106
X6	-0.138154	0.411375	0.04162	0.01352
Y6	0.06307	-0.129202	0.009942	-0.187192
Z6	0.063236	0.055484	0.077603	-0.123153
X7	0.036149	0.086747	-0.012109	-0.074096
Y7	-0.017971	-0.069444	0.078777	-0.011604
Z7	0.042386	-0.01656	0.011442	0.008459
X8	0.251629	0.019179	-0.022735	0.110892
Y8	-0.126771	-0.012821	0.008683	0.153202
Z8	0.070187	0.128242	-0.028532	0.0774
X9	0.059241	0.101608	-0.068539	-0.067355
Y9	0.07374	0.011772	0.233595	0.128856
Z9	0.037553	0.052442	0.179278	0.157206
X10	0.017759	0.116413	0.076291	0.0073
Y10	-0.015076	-0.133034	0.053432	0.025739
Z10	0.025675	-0.056299	0.063529	-0.115502
X11	0.046613	-0.144804	0.009344	-0.136229
Y11	-0.132722	0.213182	0.002661	0.147138
Z11	-0.023408	-0.003702	0.034134	0.011143
X12	-0.007358	0.27878	0.090502	-0.080844
Y12	-0.063472	-0.030265	-0.092956	0.065492
Z12	-0.024761	-0.037744	-0.000226	0.034701
X13	0.083831	0.031234	-0.01194	0.116174
Y13	-0.022882	-0.047993	-0.010617	0.048581
Z13	0.022331	0.073562	0.068319	-0.053005
X14	0.243286	-0.086924	0.056581	0.15855
Y14	-0.075119	-0.005425	-0.18294	0.097342
Z14	0.192146	0.126934	0.018732	0.090471
X15	0.090556	0.053269	0.161951	0.157964
Y15	0.06267	-0.000736	-0.17755	-0.217087
Z15	-0.178336	-0.048737	0.099786	0.134594
X16	0.187542	0.055509	0.053495	-0.021792
Y16	0.023586	0.081092	-0.024713	0.190026
Z16	-0.148814	0.070974	0.017934	-0.027631
X17	0.161846	0.096937	0.014638	0.049448

	PC36	PC37	PC38	PC39
Y17	0.031441	0.044648	-0.096096	0.111367
Z17	0.115033	-0.081442	0.034987	-0.101171
X22	-0.163157	0.046371	-0.009394	-0.104527
Y22	-0.003674	0.079604	-0.00408	0.06291
Z22	0.052388	0.007349	-0.237847	0.11217
X23	-0.137137	-0.09125	0.0522	0.168065
Y23	0.151162	0.017151	-0.028842	-0.007249
Z23	0.099273	0.002687	0.009278	-0.117495
X24	0.083696	0.068622	-0.104726	-0.069208
Y24	0.098928	0.119984	-0.057749	0.063311
Z24	-0.094774	-0.049353	0.056749	0.092408
X25	0.218938	0.080399	-0.043119	-0.003855
Y25	0.233562	0.147384	-0.13031	0.072961
Z25	0.073956	-0.085872	-0.342958	0.185199
X26	-0.02154	-0.056357	0.023212	-0.028893
Y26	-0.013205	0.029874	-0.276428	-0.038087
Z26	-0.095762	0.067244	-0.014933	0.01749
X29	0.100088	0.13841	0.077226	0.164862
Y29	-0.1575	0.091484	-0.051956	-0.011935
Z29	0.136219	-0.195935	0.012926	0.04812
X30	-0.124515	0.076941	-0.1018	-0.20755
Y30	0.00252	-0.089666	0.081769	0.016222
Z30	0.09162	0.038518	0.046152	-0.071546
X31	-0.120913	-0.025195	0.015702	-0.028958
Y31	-0.094772	0.071914	-0.084905	-0.063304
Z31	0.161836	0.044585	0.296611	-0.079746
X32	0.080604	0.147898	-0.11886	-0.006588
Y32	-0.282241	-0.154309	0.113659	0.130403
Z32	-0.073676	0.001473	0.165106	0.092994
X33	0.117462	0.150315	0.085403	0.133076
Y33	-0.017976	-0.09586	-0.115279	0.057855
Z33	0.092501	-0.108475	0.070709	0.1232
X34	0.142864	-0.012088	-0.162416	0.011803
Y34	0.061125	-0.053003	-0.036713	0.076183
Z34	-0.089959	0.056771	-0.147029	-0.281864
X37	-0.078029	0.15814	-0.03996	0.140912
Y37	-0.113192	0.050295	0.246646	0.06011
Z37	0.054096	-0.124321	0.059322	-0.011742
X38	-0.022083	0.131841	0.118195	-0.074803
Y38	-0.091645	0.092423	0.099081	-0.033653
Z38	-0.017801	-0.058456	-0.103708	-0.081916

Appendix C. Summary statistics by site.

Black Widow Ridge

Variable	N	Sum	Mean	Variance	Std Dev
PRIN1	8	0.04139	0.00517	0.0001619	0.01272
PRIN2	8	0.06512	0.00814	0.0001510	0.01229
PRIN3	8	-0.02903	-0.00363	0.0000849	0.00922
PRIN4	8	0.02303	0.00288	0.0000890	0.00943
PRIN5	8	-0.04622	-0.00578	0.0000481	0.00694
PRIN6	8	-0.07295	-0.00912	0.0000471	0.00686
PRIN7	8	-0.05942	-0.00743	0.0000512	0.00716
PRIN8	8	-0.00290	-0.0003626	0.0001044	0.01022
PRIN9	8	-0.03852	-0.00481	0.0000479	0.00692
PRIN10	8	-0.01500	-0.00187	0.0000319	0.00564
PRIN11	8	-0.01058	-0.00132	0.0000289	0.00538
PRIN12	8	-0.05038	-0.00630	0.0000507	0.00712
PRIN13	8	-0.03227	-0.00403	0.0000409	0.00639
PRIN14	8	0.01785	0.00223	0.0000241	0.00491
PRIN15	8	0.03463	0.00433	0.0000339	0.00582
PRIN16	8	-0.00293	-0.0003667	0.0000251	0.00501
PRIN17	8	-0.02200	-0.00275	0.0000525	0.00725
PRIN18	8	0.00793	0.0009915	0.0000257	0.00506
PRIN19	8	0.02667	0.00333	0.0000309	0.00556
PRIN20	8	0.01236	0.00155	0.0000276	0.00525
PRIN21	8	-0.00401	-0.0005009	0.0000232	0.00481
PRIN22	8	-0.02131	-0.00266	0.0000265	0.00515
PRIN23	8	-0.00448	-0.0005598	0.0000230	0.00480
PRIN24	8	-0.00827	-0.00103	0.0000277	0.00526
PRIN25	8	0.01514	0.00189	6.29483E-6	0.00251
PRIN26	8	-0.00212	-0.0002647	7.78329E-6	0.00279
PRIN27	8	-0.00527	-0.0006592	8.44093E-6	0.00291
PRIN28	8	0.02082	0.00260	0.0000195	0.00442
PRIN29	8	0.01137	0.00142	0.0000282	0.00531
PRIN30	8	0.01454	0.00182	0.0000139	0.00372
PRIN31	8	-0.00808	-0.00101	0.0000316	0.00562
PRIN32	8	-0.0000283	-3.5433E-6	0.0000265	0.00515
PRIN33	8	-0.00540	-0.0006750	0.0000138	0.00372
PRIN34	8	-0.00471	-0.0005888	0.0000258	0.00508
PRIN35	8	-0.01101	-0.00138	8.37203E-6	0.00289

PRIN36	8	0.01315	0.00164	0.0000132	0.00364
PRIN37	8	-0.00646	-0.0008074	5.98988E-6	0.00245
PRIN38	8	-0.01080	-0.00135	8.51244E-6	0.00292
PRIN39	8	0.01548	0.00193	7.38466E-6	0.00272

Cheyenne River

Variable	N	Sum	Mean	Variance	Std Dev
PRIN1	18	0.10481	0.00582	0.0001736	0.01317
PRIN2	18	0.06549	0.00364	0.0001260	0.01122
PRIN3	18	0.11946	0.00664	0.0002406	0.01551
PRIN4	18	0.01644	0.0009134	0.0001008	0.01004
PRIN5	18	-0.12068	-0.00670	0.0000560	0.00748
PRIN6	18	0.04230	0.00235	0.0001047	0.01023
PRIN7	18	0.03243	0.00180	0.0000554	0.00744
PRIN8	18	-0.03982	-0.00221	0.0000622	0.00788
PRIN9	18	0.00244	0.0001353	0.0000561	0.00749
PRIN10	18	-0.04412	-0.00245	0.0000506	0.00711
PRIN11	18	-0.01078	-0.0005987	0.0000559	0.00748
PRIN12	18	0.04910	0.00273	0.0000556	0.00746
PRIN13	18	0.01641	0.0009115	0.0000344	0.00587
PRIN14	18	-0.00903	-0.0005019	0.0000662	0.00814
PRIN15	18	0.02842	0.00158	0.0000440	0.00663
PRIN16	18	0.05413	0.00301	0.0000335	0.00579
PRIN17	18	-0.01446	-0.0008036	0.0000370	0.00609
PRIN18	18	0.04564	0.00254	0.0000224	0.00473
PRIN19	18	0.03132	0.00174	0.0000460	0.00679
PRIN20	18	-0.00474	-0.0002635	0.0000185	0.00430
PRIN21	18	-0.02229	-0.00124	0.0000260	0.00510
PRIN22	18	-0.01709	-0.0009495	7.51215E-6	0.00274
PRIN23	18	0.01822	0.00101	0.0000205	0.00453
PRIN24	18	-0.00425	-0.0002362	0.0000352	0.00593
PRIN25	18	-0.00492	-0.0002733	0.0000165	0.00406
PRIN26	18	-0.02678	-0.00149	0.0000139	0.00373
PRIN27	18	0.02019	0.00112	0.0000148	0.00384
PRIN28	18	0.00211	0.0001173	0.0000191	0.00437
PRIN29	18	-0.01776	-0.0009868	0.0000187	0.00432
PRIN30	18	-0.01594	-0.0008856	6.78871E-6	0.00261

PRIN31	18	-0.01636	-0.0009090	0.0000150	0.00387
PRIN32	18	0.02589	0.00144	8.84911E-6	0.00297
PRIN33	18	-0.00335	-0.0001861	0.0000105	0.00324
PRIN34	18	0.00459	0.0002548	6.54789E-6	0.00256
PRIN35	18	0.01491	0.0008283	6.73152E-6	0.00259
PRIN36	18	0.03481	0.00193	0.0000201	0.00448
PRIN37	18	0.00246	0.0001368	0.0000110	0.00331
PRIN38	18	-0.00622	-0.0003454	7.21472E-6	0.00269
PRIN39	18	0.0004982	0.0000277	4.90331E-6	0.00221

Indian Creek

Variable	N	Sum	Mean	Variance	Std Dev
PRIN1	2	-0.03128	-0.01564	0.0000171	0.00413
PRIN2	2	-0.00349	-0.00175	0.0000934	0.00967
PRIN3	2	-0.01179	-0.00589	0.0002258	0.01503
PRIN4	2	-0.01057	-0.00529	0.0000144	0.00379
PRIN5	2	-0.02255	-0.01127	0.0000415	0.00645
PRIN6	2	-0.00845	-0.00422	0.0000553	0.00744
PRIN7	2	-0.01242	-0.00621	0.0000234	0.00483
PRIN8	2	0.00415	0.00207	0.0000275	0.00524
PRIN9	2	0.01499	0.00750	0.0001284	0.01133
PRIN10	2	-0.00253	-0.00126	0.0000172	0.00415
PRIN11	2	0.00369	0.00185	6.67945E-6	0.00258
PRIN12	2	0.00741	0.00371	2.6998E-10	0.0000164
PRIN13	2	-0.0000528	-0.0000264	0.0000239	0.00489
PRIN14	2	-0.01942	-0.00971	7.36761E-6	0.00271
PRIN15	2	-0.0008807	-0.0004403	0.0000313	0.00560
PRIN16	2	0.00500	0.00250	1.1847E-10	0.0000109
PRIN17	2	0.01062	0.00531	7.80228E-6	0.00279
PRIN18	2	0.00278	0.00139	4.98183E-6	0.00223
PRIN19	2	-0.00930	-0.00465	0.0000995	0.00998
PRIN20	2	0.00315	0.00157	8.18635E-6	0.00286
PRIN21	2	-0.00321	-0.00160	3.18081E-6	0.00178
PRIN22	2	-0.00279	-0.00139	7.7957E-6	0.00279
PRIN23	2	-0.00115	-0.0005774	7.94676E-6	0.00282
PRIN24	2	-0.00724	-0.00362	0.0000393	0.00627
PRIN25	2	-0.00128	-0.0006392	0.0000583	0.00764

PRIN26	2	-0.00414	-0.00207	1.21518E-6	0.00110
PRIN27	2	-0.00393	-0.00196	0.0000372	0.00610
PRIN28	2	-0.00452	-0.00226	7.55838E-6	0.00275
PRIN29	2	0.00340	0.00170	0.0001346	0.01160
PRIN30	2	-0.00227	-0.00114	3.84476E-6	0.00196
PRIN31	2	-0.00672	-0.00336	2.25531E-6	0.00150
PRIN32	2	7.72574E-7	3.86287E-7	0.0000425	0.00652
PRIN33	2	-0.00697	-0.00349	7.98082E-6	0.00283
PRIN34	2	-0.00488	-0.00244	9.63411E-7	0.0009815
PRIN35	2	0.00278	0.00139	0.0000134	0.00367
PRIN36	2	0.00729	0.00365	7.50991E-6	0.00274
PRIN37	2	-0.00921	-0.00461	0.0000147	0.00384
PRIN38	2	-0.00747	-0.00373	0.0000643	0.00802
PRIN39	2	-0.00795	-0.00397	0.0000423	0.00651

Larson

Variable	N	Sum	Mean	Variance	Std Dev
PRIN1	129	-0.17828	-0.00138	0.0001392	0.01180
PRIN2	129	-0.73500	-0.00570	0.0001062	0.01031
PRIN3	129	-0.45674	-0.00354	0.0001128	0.01062
PRIN4	129	-0.08078	-0.0006262	0.0000960	0.00980
PRIN5	129	0.05980	0.0004636	0.0000971	0.00985
PRIN6	129	0.12638	0.0009797	0.0000766	0.00875
PRIN7	129	0.22096	0.00171	0.0000759	0.00871
PRIN8	129	0.20452	0.00159	0.0000754	0.00868
PRIN9	129	0.11710	0.0009078	0.0000440	0.00663
PRIN10	129	0.13008	0.00101	0.0000526	0.00725
PRIN11	129	0.04067	0.0003153	0.0000512	0.00715
PRIN12	129	-0.13547	-0.00105	0.0000417	0.00646
PRIN13	129	-0.20628	-0.00160	0.0000490	0.00700
PRIN14	129	-0.07831	-0.0006071	0.0000415	0.00644
PRIN15	129	0.08340	0.0006465	0.0000325	0.00570
PRIN16	129	-0.09419	-0.0007301	0.0000330	0.00574
PRIN17	129	-0.13425	-0.00104	0.0000320	0.00566
PRIN18	129	-0.02013	-0.0001560	0.0000327	0.00572
PRIN19	129	0.03651	0.0002831	0.0000202	0.00449
PRIN20	129	0.07065	0.0005477	0.0000232	0.00482
PRIN21	129	-0.08742	-0.0006777	0.0000276	0.00525

PRIN22	129	0.00551	0.0000427	0.0000234	0.00483
PRIN23	129	-0.03390	-0.0002628	0.0000209	0.00457
PRIN24	129	0.01638	0.0001269	0.0000234	0.00484
PRIN25	129	-0.00370	-0.0002612	0.0000228	0.00478
PRIN26	129	0.06005	0.0004655	0.0000228	0.00477
PRIN27	129	0.04551	0.0003528	0.0000184	0.00429
PRIN28	129	0.02924	0.0002267	0.0000211	0.00459
PRIN29	129	-0.02004	-0.0001554	0.0000141	0.00375
PRIN30	129	0.03703	0.0002871	0.0000185	0.00430
PRIN31	129	0.05939	0.0004604	0.0000118	0.00344
PRIN32	129	0.10204	0.0007910	0.0000151	0.00388
PRIN33	129	0.07749	0.0006007	0.0000132	0.00363
PRIN34	129	-0.01644	-0.0001274	0.0000141	0.00375
PRIN35	129	0.05434	0.0004212	0.0000141	0.00376
PRIN36	129	0.05628	0.0004363	0.0000101	0.00318
PRIN37	129	0.04914	0.0003809	0.0000127	0.00357
PRIN38	129	0.02839	0.0002201	0.0000105	0.00324
PRIN39	129	-0.00279	-0.0000216	0.0000105	0.00325

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Leavitt

Variable	N	Sum	Mean	Variance	Std Dev
PRIN1	5	-0.01802	-0.00360	0.0000304	0.00551
PRIN2	5	0.02095	0.00419	0.0000283	0.00532
PRIN3	5	0.03866	0.00773	0.0000883	0.00940
PRIN4	5	-0.00176	-0.0003523	0.0000523	0.00723
PRIN5	5	-0.02696	-0.00539	0.0000321	0.00567
PRIN6	5	-0.02768	-0.00554	0.0000464	0.00681
PRIN7	5	0.00669	0.00134	7.26913E-6	0.00270
PRIN8	5	-0.02575	-0.00515	0.0000200	0.00447
PRIN9	5	0.00582	0.00116	0.0000680	0.00825
PRIN10	5	-0.02078	-0.00416	0.0000187	0.00433
PRIN11	5	0.05161	0.01032	0.0000501	0.00708
PRIN12	5	0.01483	0.00297	0.0000431	0.00657
PRIN13	5	-0.00405	-0.0008095	0.0000660	0.00812
PRIN14	5	0.00566	0.00113	2.13893E-6	0.00146
PRIN15	5	0.0001149	0.0000230	5.72719E-6	0.00239
PRIN16	5	0.02059	0.00412	0.0000353	0.00594

PRIN17	5	-0.00429	-0.0008583	0.0000335	0.00579
PRIN18	5	-0.00313	-0.0006269	0.0000122	0.00350
PRIN19	5	0.00730	0.00146	0.0000129	0.00359
PRIN20	5	-0.00660	-0.00132	0.0000235	0.00485
PRIN21	5	-0.03996	-0.00799	0.0000123	0.00351
PRIN22	5	0.01190	0.00238	0.0000275	0.00525
PRIN23	5	0.01880	0.00376	0.0000197	0.00444
PRIN24	5	0.00314	0.0006286	0.0000304	0.00551
PRIN25	5	-0.00778	-0.00156	0.0000121	0.00348
PRIN26	5	-0.01854	-0.00371	0.0000306	0.00553
PRIN27	5	-0.00259	-0.0005174	3.69509E-6	0.00192
PRIN28	5	0.00398	0.0007959	0.0000185	0.00430
PRIN29	5	-0.01578	-0.00316	0.0000101	0.00318
PRIN30	5	-0.00821	-0.00164	0.0000315	0.00562
PRIN31	5	-0.00112	-0.0002248	0.0000244	0.00494
PRIN32	5	0.0005555	0.0001111	5.66213E-6	0.00238
PRIN33	5	0.00105	0.0002106	6.29492E-6	0.00251
PRIN34	5	-0.00189	-0.0003783	0.0000113	0.00335
PRIN35	5	-0.00797	-0.00159	5.33957E-6	0.00231
PRIN36	5	-0.00100	-0.0002009	4.24968E-6	0.00206
PRIN37	5	-0.00766	-0.00153	7.95317E-6	0.00282
PRIN38	5	-0.00725	-0.00145	9.26389E-6	0.00304
PRIN39	5	-0.00500	-0.0009998	4.44987E-6	0.00211

Leavenworth

Variable	N	Sum	Mean	Variance	Std Dev
PRIN1	44	0.04008	0.0009109	0.0001638	0.01280
PRIN2	44	0.05683	0.00129	0.0001289	0.01135
PRIN3	44	0.18890	0.00429	0.0000868	0.00932
PRIN4	44	0.16374	0.00372	0.0001381	0.01175
PRIN5	44	0.15569	0.00354	0.0000867	0.00931
PRIN6	44	-0.03420	-0.0007773	0.0000642	0.00801
PRIN7	44	0.13772	0.00313	0.0000491	0.00700
PRIN8	44	0.08202	0.00186	0.0000538	0.00733
PRIN9	44	-0.12121	-0.00275	0.0000362	0.00602
PRIN10	44	0.02997	0.0006811	0.0000347	0.00589
PRIN11	44	0.01868	0.0004246	0.0000504	0.00710

PRIN12	44	-0.01337	-0.0003039	0.0000539	0.00734
PRIN13	44	0.05390	0.00123	0.0000351	0.00592
PRIN14	44	-0.09276	-0.00211	0.0000364	0.00603
PRIN15	44	-0.01925	-0.0004375	0.0000330	0.00574
PRIN16	44	0.06036	0.00137	0.0000380	0.00617
PRIN17	44	-0.02397	-0.0005448	0.0000263	0.00512
PRIN18	44	-0.05417	-0.00123	0.0000207	0.00455
PRIN19	44	-0.00169	-0.0000384	0.0000237	0.00487
PRIN20	44	-0.12523	-0.00285	0.0000204	0.00452
PRIN21	44	-0.04824	-0.00110	0.0000259	0.00509
PRIN22	44	0.02046	0.0004651	0.0000196	0.00443
PRIN23	44	-0.01808	-0.0004110	0.0000252	0.00502
PRIN24	44	0.06063	0.00138	0.0000222	0.00471
PRIN25	44	-0.03326	-0.0007559	0.0000207	0.00455
PRIN26	44	0.02867	0.0006517	0.0000185	0.00431
PRIN27	44	-0.01659	-0.0003770	0.0000187	0.00432
PRIN28	44	-0.03428	-0.0007792	0.0000171	0.00414
PRIN29	44	0.02633	0.0005984	0.0000182	0.00427
PRIN30	44	-0.00140	-0.0000318	0.0000150	0.00387
PRIN31	44	-0.03106	-0.0007059	0.0000144	0.00380
PRIN32	44	0.01812	0.0004117	0.0000157	0.00396
PRIN33	44	0.04629	0.00105	0.0000143	0.00378
PRIN34	44	-0.04798	-0.00109	0.0000115	0.00339
PRIN35	44	-0.00169	-0.0000383	0.0000135	0.00368
PRIN36	44	-0.00720	-0.0001636	0.0000150	0.00388
PRIN37	44	0.04404	0.00100	9.66788E-6	0.00311
PRIN38	44	0.04889	0.00111	0.0000120	0.00347
PRIN39	44	-0.04705	-0.00107	0.0000105	0.00325

Mobridge F1

Variable	N	Sum	Mean	Variance	Std Dev
PRIN1	31	-0.15212	-0.00491	0.0001861	0.01364
PRIN2	31	0.04572	0.00147	0.0001752	0.01324
PRIN3	31	0.06831	0.00220	0.0001216	0.01103
PRIN4	31	-0.13207	-0.00426	0.0000860	0.00928
PRIN5	31	0.16684	0.00538	0.0000676	0.00822
PRIN6	31	0.05402	0.00174	0.0001215	0.01102

PRIN7	31	0.07169	0.00231	0.0000701	0.00837
PRIN8	31	0.01287	0.0004152	0.0000834	0.00913
PRIN9	31	0.06220	0.00201	0.0000564	0.00751
PRIN10	31	-0.05012	-0.00162	0.0000654	0.00809
PRIN11	31	-0.08025	-0.00259	0.0000531	0.00729
PRIN12	31	0.06011	0.00194	0.0000223	0.00472
PRIN13	31	0.00702	0.0002263	0.0000488	0.00699
PRIN14	31	0.00423	0.0001363	0.0000365	0.00605
PRIN15	31	-0.01519	-0.0004899	0.0000432	0.00658
PRIN16	31	-0.03753	-0.00121	0.0000295	0.00544
PRIN17	31	0.08810	0.00284	0.0000586	0.00766
PRIN18	31	0.05716	0.00184	0.0000296	0.00544
PRIN19	31	0.03430	0.00111	0.0000253	0.00503
PRIN20	31	-0.02381	-0.0007680	0.0000313	0.00560
PRIN21	31	0.05531	0.00178	0.0000319	0.00565
PRIN22	31	0.01770	0.0005711	0.0000168	0.00409
PRIN23	31	-0.01442	-0.0004652	0.0000191	0.00437
PRIN24	31	0.00687	0.0002215	0.0000233	0.00483
PRIN25	31	0.00742	0.0002394	0.0000124	0.00352
PRIN26	31	0.01553	0.0005010	0.0000135	0.00368
PRIN27	31	-0.0001514	-4.8838E-6	0.0000154	0.00393
PRIN28	31	0.01845	0.0005951	0.0000191	0.00437
PRIN29	31	-0.02767	-0.0008924	8.55334E-6	0.00292
PRIN30	31	0.01320	0.0004257	0.0000274	0.00524
PRIN31	31	-0.02052	-0.0006621	0.0000148	0.00385
PRIN32	31	-0.03655	-0.00118	8.17011E-6	0.00286
PRIN33	31	0.02834	0.0009140	9.22646E-6	0.00304
PRIN34	31	-0.01224	-0.0003948	7.34191E-6	0.00271
PRIN35	31	0.01751	0.0005650	0.0000121	0.00348
PRIN36	31	-0.04283	-0.00138	5.92557E-6	0.00243
PRIN37	31	0.01169	0.0003771	9.91123E-6	0.00315
PRIN38	31	-0.03064	-0.0009884	9.16569E-6	0.00303
PRIN39	31	0.03502	0.00113	0.0000116	0.00340

Mobridge F2

Variable	N	Sum	Mean	Variance	Std Dev
PRIN1	85	0.10653	0.00125	0.0001557	0.01248
PRIN2	85	0.16972	0.00200	0.0001280	0.01131
PRIN3	85	-0.02908	-0.0003421	0.0000839	0.00916
PRIN4	85	0.06957	0.0008184	0.0001086	0.01042
PRIN5	85	0.05411	0.0006366	0.0001075	0.01037
PRIN6	85	0.16194	0.00191	0.0001038	0.01019
PRIN7	85	-0.20215	-0.00238	0.0001054	0.01027
PRIN8	85	-0.05355	-0.0006300	0.0000928	0.00963
PRIN9	85	-0.05150	-0.0006059	0.0000586	0.00765
PRIN10	85	0.05764	0.0006782	0.0000646	0.00804
PRIN11	85	0.00655	0.0000770	0.0000422	0.00649
PRIN12	85	0.04634	0.0005452	0.0000470	0.00685
PRIN13	85	0.12194	0.00143	0.0000429	0.00655
PRIN14	85	-0.06423	-0.0007556	0.0000372	0.00610
PRIN15	85	-0.07435	-0.0008747	0.0000365	0.00604
PRIN16	85	-0.10288	-0.00121	0.0000296	0.00544
PRIN17	85	-0.02788	-0.0003280	0.0000293	0.00541
PRIN18	85	0.02211	0.0002602	0.0000362	0.00602
PRIN19	85	-0.04294	-0.0005052	0.0000336	0.00579
PRIN20	85	0.02414	0.0002840	0.0000322	0.00567
PRIN21	85	0.11063	0.00130	0.0000233	0.00483
PRIN22	85	-0.04940	-0.0005812	0.0000253	0.00503
PRIN23	85	-0.00697	-0.0000820	0.0000269	0.00518
PRIN24	85	-0.04020	-0.0004730	0.0000217	0.00466
PRIN25	85	0.09592	0.00113	0.0000240	0.00490
PRIN26	85	-0.04487	-0.0005279	0.0000133	0.00364
PRIN27	85	-0.07240	-0.0008517	0.0000200	0.00447
PRIN28	85	0.03667	0.0004314	0.0000142	0.00377
PRIN29	85	0.00504	0.0000593	0.0000138	0.00371
PRIN30	85	0.01420	0.0001671	0.0000150	0.00387
PRIN31	85	0.05260	0.0006188	0.0000148	0.00385
PRIN32	85	0.01507	0.0001773	0.0000100	0.00317
PRIN33	85	-0.00945	-0.0001111	0.0000114	0.00338
PRIN34	85	0.04763	0.0005604	0.0000114	0.00337
PRIN35	85	-0.11238	-0.00132	0.0000112	0.00334
PRIN36	85	-0.02380	-0.0002800	0.0000119	0.00345

PRIN37	85	-0.02413	-0.0002839	0.0000117	0.00342
PRIN38	85	0.02468	0.0002904	9.31034E-6	0.00305
PRIN39	85	-0.04766	-0.0005607	0.0000101	0.00318

Mobridge F3

Variable	N	Sum	Mean	Variance	Std Dev
PRIN1	8	-0.00961	-0.00120	0.0001689	0.01299
PRIN2	8	0.03542	0.00443	0.0000931	0.00965
PRIN3	8	0.06294	0.00787	0.0001261	0.01123
PRIN4	8	-0.03832	-0.00479	0.0001309	0.01144
PRIN5	8	0.05265	0.00658	0.0000913	0.00956
PRIN6	8	0.01147	0.00143	0.0000286	0.00535
PRIN7	8	0.01858	0.00232	0.0000242	0.00492
PRIN8	8	-0.00243	-0.0003036	0.0000426	0.00653
PRIN9	8	0.02985	0.00373	0.0000537	0.00733
PRIN10	8	-0.00824	-0.00103	0.0000218	0.00467
PRIN11	8	0.00637	0.0007961	0.0000362	0.00602
PRIN12	8	-0.01020	-0.00127	0.0000796	0.00892
PRIN13	8	-0.00139	-0.0001732	0.0000495	0.00703
PRIN14	8	0.01087	0.00136	0.0000136	0.00369
PRIN15	8	-0.01624	-0.00203	0.0000189	0.00435
PRIN16	8	-0.00607	-0.0007593	0.0000219	0.00468
PRIN17	8	0.03872	0.00484	0.0000165	0.00406
PRIN18	8	0.00387	0.0004833	0.0000145	0.00381
PRIN19	8	-0.00311	-0.0003890	9.40015E-6	0.00307
PRIN20	8	0.00497	0.0006209	0.0000257	0.00507
PRIN21	8	-0.00531	-0.0006633	0.0000289	0.00538
PRIN22	8	0.01960	0.00245	0.0000315	0.00562
PRIN23	8	-0.01354	-0.00169	0.0000260	0.00509
PRIN24	8	0.01132	0.00141	0.0000190	0.00436
PRIN25	8	-0.01504	-0.00188	0.0000203	0.00451
PRIN26	8	-0.01245	-0.00156	0.0000128	0.00358
PRIN27	8	0.00949	0.00119	8.22296E-6	0.00287
PRIN28	8	0.00869	0.00109	0.0000225	0.00474
PRIN29	8	-0.01155	-0.00144	0.0000303	0.00550
PRIN30	8	-0.01775	-0.00222	0.0000209	0.00458
PRIN31	8	-0.00908	-0.00114	0.0000104	0.00323

PRIN32	8	-0.02592	-0.00324	3.38437E-6	0.00184
PRIN33	8	-0.01145	-0.00143	0.0000167	0.00409
PRIN34	8	-0.00215	-0.0002687	6.1402E-6	0.00248
PRIN35	8	0.01483	0.00185	6.09197E-6	0.00247
PRIN36	8	-0.00647	-0.0008086	0.0000210	0.00459
PRIN37	8	0.01041	0.00130	4.06379E-6	0.00202
PRIN38	8	0.00483	0.0006040	8.98626E-6	0.00300
PRIN39	8	0.00532	0.0006652	3.5138E-6	0.00187

Nordvold 1

Variable	N	Sum	Mean	Variance	Std Dev
PRIN1	3	0.00493	0.00164	0.0000154	0.00392
PRIN2	3	0.01327	0.00442	0.0001576	0.01256
PRIN3	3	0.0009544	0.0003181	0.0000730	0.00854
PRIN4	3	-0.00691	-0.00230	7.96646E-6	0.00282
PRIN5	3	-0.00424	-0.00141	0.0000247	0.00497
PRIN6	3	-0.00768	-0.00256	0.0000108	0.00329
PRIN7	3	0.00565	0.00188	8.44644E-6	0.00291
PRIN8	3	0.0003260	0.0001087	0.0000284	0.00533
PRIN9	3	0.00844	0.00281	0.0000217	0.00466
PRIN10	3	-0.00946	-0.00315	0.0000176	0.00420
PRIN11	3	0.00555	0.00185	0.0000238	0.00488
PRIN12	3	-0.02781	-0.00927	0.0001078	0.01038
PRIN13	3	0.00547	0.00182	0.0001111	0.01054
PRIN14	3	-0.01204	-0.00401	1.558E-6	0.00125
PRIN15	3	-0.0007488	-0.0002496	0.0000196	0.00443
PRIN16	3	0.00795	0.00265	0.0000284	0.00532
PRIN17	3	0.00304	0.00101	2.08337E-6	0.00144
PRIN18	3	-0.01619	-0.00540	0.0000578	0.00760
PRIN19	3	0.00618	0.00206	0.0000958	0.00979
PRIN20	3	-0.00442	-0.00147	0.0000214	0.00463
PRIN21	3	-0.00373	-0.00124	0.0000120	0.00346
PRIN22	3	-0.01639	-0.00546	7.58188E-6	0.00275
PRIN23	3	0.00210	0.0006985	0.0000113	0.00335
PRIN24	3	-0.00688	-0.00229	0.0000389	0.00624
PRIN25	3	0.0006934	0.0002311	0.0000160	0.00400
PRIN26	3	-0.01057	-0.00352	0.0000154	0.00393

PRIN27	3	-0.00792	-0.00264	5.34237E-6	0.00231
PRIN28	3	-0.00545	-0.00182	0.0000256	0.00506
PRIN29	3	0.01428	0.00476	7.68086E-6	0.00277
PRIN30	3	-0.0003063	-0.0001021	0.0000154	0.00393
PRIN31	3	0.00274	0.0009134	0.0000229	0.00478
PRIN32	3	-0.00349	-0.00116	5.00566E-6	0.00224
PRIN33	3	-0.00988	-0.00329	0.0000499	0.00706
PRIN34	3	0.00456	0.00152	8.59931E-6	0.00293
PRIN35	3	-0.00373	-0.00124	1.97677E-6	0.00141
PRIN36	3	-0.00399	-0.00133	1.20379E-6	0.00110
PRIN37	3	-0.00722	-0.00241	0.0000184	0.00429
PRIN38	3	-0.00458	-0.00153	0.0000112	0.00334
PRIN39	3	0.00506	0.00169	9.13345E-7	0.0009557

Nordvold 2&3

Variable	N	Sum	Mean	Variance	Std Dev
PRIN1	27	-0.02763	-0.00102	0.0002125	0.01458
PRIN2	27	0.03782	0.00140	0.0001785	0.01336
PRIN3	27	0.05489	0.00203	0.0001740	0.01319
PRIN4	27	0.08657	0.00321	0.0001125	0.01061
PRIN5	27	-0.17277	-0.00640	0.0001307	0.01143
PRIN6	27	-0.06597	-0.00244	0.0000860	0.00927
PRIN7	27	0.08436	0.00312	0.0001191	0.01092
PRIN8	27	0.03767	0.00140	0.0001132	0.01064
PRIN9	27	-0.01869	-0.0006921	0.0000728	0.00853
PRIN10	27	0.00207	0.0000768	0.0000409	0.00639
PRIN11	27	-0.02814	-0.00104	0.0000455	0.00674
PRIN12	27	0.06152	0.00228	0.0000367	0.00606
PRIN13	27	0.03390	0.00126	0.0000315	0.00561
PRIN14	27	0.04835	0.00179	0.0000265	0.00515
PRIN15	27	-0.01539	-0.0005701	0.0000478	0.00692
PRIN16	27	0.07430	0.00275	0.0000425	0.00652
PRIN17	27	-0.01907	-0.0007064	0.0000397	0.00630
PRIN18	27	-0.02068	-0.0007659	0.0000408	0.00639
PRIN19	27	-0.01793	-0.0006642	0.0000334	0.00578
PRIN20	27	0.02958	0.00110	0.0000332	0.00576
PRIN21	27	-0.03070	-0.00114	0.0000215	0.00463

PRIN22	27	0.01477	0.0005469	0.0000183	0.00427
PRIN23	27	0.02977	0.00110	0.0000338	0.00581
PRIN24	27	0.00929	0.0003440	0.0000179	0.00424
PRIN25	27	-0.01090	-0.0004039	0.0000177	0.00420
PRIN26	27	0.00556	0.0002060	0.0000148	0.00385
PRIN27	27	-0.00965	-0.0003574	0.0000297	0.00545
PRIN28	27	0.00548	0.0002030	0.0000224	0.00473
PRIN29	27	0.07547	0.00280	0.0000118	0.00343
PRIN30	27	0.00460	0.0001704	0.0000137	0.00370
PRIN31	27	-0.02724	-0.00101	0.0000259	0.00509
PRIN32	27	-0.02817	-0.00104	0.0000108	0.00329
PRIN33	27	-0.01718	-0.0006364	0.0000135	0.00368
PRIN34	27	0.01247	0.0004620	0.0000108	0.00329
PRIN35	27	-0.01418	-0.0005251	0.0000149	0.00387
PRIN36	27	-0.00818	-0.0003029	0.0000121	0.00348
PRIN37	27	-0.01396	-0.0005171	9.89179E-6	0.00315
PRIN38	27	0.03306	0.00122	0.0000167	0.00409
PRIN39	27	0.00144	0.0000534	6.56083E-6	0.00256

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Rygh

Variable	N	Sum	Mean	Variance	Std Dev
PRIN1	23	-0.12179	-0.00530	0.0002014	0.01419
PRIN2	23	0.05418	0.00236	0.0002191	0.01480
PRIN3	23	-0.03009	-0.00131	0.0000684	0.00827
PRIN4	23	-0.04417	-0.00192	0.0001255	0.01120
PRIN5	23	0.06250	0.00272	0.0001184	0.01088
PRIN6	23	-0.06530	-0.00284	0.0001407	0.01186
PRIN7	23	-0.02361	-0.00103	0.0000863	0.00929
PRIN8	23	-0.00863	-0.0003751	0.0000449	0.00670
PRIN9	23	0.11323	0.00492	0.0001423	0.01193
PRIN10	23	-0.01244	-0.0005410	0.0000448	0.00670
PRIN11	23	0.04450	0.00193	0.0000916	0.00957
PRIN12	23	-0.04541	-0.00197	0.0000509	0.00713
PRIN13	23	-0.02790	-0.00121	0.0000355	0.00596
PRIN14	23	0.02016	0.0008767	0.0000535	0.00731
PRIN15	23	-0.04236	-0.00184	0.0000282	0.00531
PRIN16	23	-0.05320	-0.00231	0.0000540	0.00735

PRIN17	23	0.01591	0.0006916	0.0000326	0.00571
PRIN18	23	-0.01501	-0.0006524	0.0000241	0.00491
PRIN19	23	-0.01755	-0.0007629	0.0000487	0.00698
PRIN20	23	-0.05258	-0.00229	0.0000246	0.00496
PRIN21	23	0.03313	0.00144	0.0000192	0.00438
PRIN22	23	-0.06231	-0.00271	0.0000213	0.00462
PRIN23	23	-0.03016	-0.00131	0.0000364	0.00603
PRIN24	23	-0.01419	-0.0006170	0.0000168	0.00410
PRIN25	23	0.01268	0.0005511	0.0000250	0.00500
PRIN26	23	-0.02884	-0.00125	0.0000109	0.00331
PRIN27	23	0.03047	0.00132	0.0000152	0.00389
PRIN28	23	-0.01705	-0.0007412	0.0000192	0.00439
PRIN29	23	0.01882	0.0008184	0.0000236	0.00486
PRIN30	23	-0.01792	-0.0007791	0.0000140	0.00375
PRIN31	23	0.01242	0.0005401	9.92321E-6	0.00315
PRIN32	23	-0.03654	-0.00159	0.0000163	0.00404
PRIN33	23	-0.01259	-0.0005474	0.0000238	0.00488
PRIN34	23	-0.00809	-0.0003517	0.0000176	0.00420
PRIN35	23	0.01771	0.0007699	0.0000135	0.00368
PRIN36	23	-0.02801	-0.00122	0.0000120	0.00347
PRIN37	23	-0.01559	-0.0006777	0.0000102	0.00320
PRIN38	23	-0.04268	-0.00186	6.59895E-6	0.00257
PRIN39	23	0.02749	0.00120	0.0000178	0.00422

Swan Creek

Variable	N	Sum	Mean	Variance	Std Dev
PRIN1	12	0.08967	0.00747	0.0002959	0.01720
PRIN2	12	-0.04582	-0.00382	0.0001365	0.01168
PRIN3	12	0.01968	0.00164	0.0001950	0.01396
PRIN4	12	0.06937	0.00578	0.0001136	0.01066
PRIN5	12	-0.04612	-0.00384	0.0001010	0.01005
PRIN6	12	-0.01433	-0.00119	0.0000250	0.00500
PRIN7	12	-0.00253	-0.0002111	0.0001384	0.01176
PRIN8	12	0.06815	0.00568	0.0000782	0.00884
PRIN9	12	0.02645	0.00220	0.0000337	0.00580
PRIN10	12	-0.03541	-0.00295	0.0000640	0.00800
PRIN11	12	-0.00694	-0.0005784	0.0000436	0.00660

PRIN12	12	0.02892	0.00241	0.0000198	0.00445
PRIN13	12	-0.00111	-0.0000929	0.0000477	0.00691
PRIN14	12	-0.01114	-0.0009281	0.0000217	0.00466
PRIN15	12	0.01661	0.00138	7.71304E-6	0.00278
PRIN16	12	0.05439	0.00453	0.0000424	0.00651
PRIN17	12	0.02014	0.00168	9.83919E-6	0.00314
PRIN18	12	-0.00330	-0.0002752	0.0000337	0.00581
PRIN19	12	-0.04165	-0.00347	0.0000212	0.00460
PRIN20	12	0.00242	0.0002019	0.0000343	0.00586
PRIN21	12	-0.01324	-0.00110	0.0000265	0.00515
PRIN22	12	-0.00346	-0.0002880	0.0000242	0.00492
PRIN23	12	0.02757	0.00230	0.0000138	0.00371
PRIN24	12	0.01354	0.00113	0.0000137	0.00371
PRIN25	12	-0.00178	-0.0001482	0.0000115	0.00339
PRIN26	12	-0.05544	-0.00462	6.85479E-6	0.00262
PRIN27	12	-0.00207	-0.0001725	0.0000275	0.00525
PRIN28	12	0.01374	0.00115	7.26299E-6	0.00269
PRIN29	12	0.02126	0.00177	9.76787E-6	0.00313
PRIN30	12	-0.00123	-0.0001024	5.72941E-6	0.00239
PRIN31	12	-0.0009689	-0.0000807	0.0000154	0.00392
PRIN32	12	-0.00443	-0.0003695	0.0000130	0.00360
PRIN33	12	-0.01030	-0.0008586	0.0000152	0.00389
PRIN34	12	-0.00659	-0.0005488	0.0000155	0.00394
PRIN35	12	-0.0001174	-9.7797E-6	0.0000161	0.00402
PRIN36	12	-0.00835	-0.0006961	8.85647E-6	0.00298
PRIN37	12	-0.00284	-0.0002366	0.0000123	0.00350
PRIN38	12	-0.00497	-0.0004138	0.0000101	0.00318
PRIN39	12	0.00700	0.0005831	8.33001E-6	0.00289

Sully A

Variable	N	Sum	Mean	Variance	Std Dev
PRIN1	17	0.10896	0.00641	0.0002189	0.01479
PRIN2	17	0.03844	0.00226	0.0001527	0.01236
PRIN3	17	0.03387	0.00199	0.0001351	0.01162
PRIN4	17	-0.05694	-0.00335	0.0001051	0.01025
PRIN5	17	-0.02934	-0.00173	0.0000724	0.00851
PRIN6	17	-0.03887	-0.00229	0.0000897	0.00947
PRIN7	17	-0.07903	-0.00465	0.0000673	0.00820

PRIN8	17	-0.06633	-0.00390	0.0000722	0.00849
PRIN9	17	-0.02675	-0.00157	0.0000539	0.00734
PRIN10	17	-0.02090	-0.00123	0.0000623	0.00789
PRIN11	17	0.00745	0.0004381	0.0000576	0.00759
PRIN12	17	-0.03715	-0.00219	0.0000321	0.00567
PRIN13	17	0.01343	0.0007899	0.0000359	0.00599
PRIN14	17	0.03608	0.00212	0.0000195	0.00441
PRIN15	17	0.0009382	0.0000552	0.0000287	0.00536
PRIN16	17	0.00587	0.0003450	0.0000269	0.00518
PRIN17	17	0.03574	0.00210	0.0000419	0.00647
PRIN18	17	-0.00242	-0.0001425	0.0000204	0.00451
PRIN19	17	0.00838	0.0004930	0.0000364	0.00603
PRIN20	17	0.02940	0.00173	0.0000375	0.00612
PRIN21	17	0.01468	0.0008633	0.0000262	0.00512
PRIN22	17	0.02515	0.00148	0.0000289	0.00538
PRIN23	17	0.02809	0.00165	0.0000150	0.00388
PRIN24	17	-0.00457	-0.0002689	0.0000250	0.00500
PRIN25	17	-0.04931	-0.00290	0.0000222	0.00472
PRIN26	17	-0.01656	-0.0009741	0.0000203	0.00450
PRIN27	17	0.02026	0.00119	0.0000191	0.00437
PRIN28	17	-0.02652	-0.00156	6.35261E-6	0.00252
PRIN29	17	0.04386	0.00258	0.0000171	0.00413
PRIN30	17	-0.00564	-0.0003318	0.0000132	0.00364
PRIN31	17	0.00182	0.0001071	0.0000243	0.00493
PRIN32	17	-0.02088	-0.00123	0.0000373	0.00611
PRIN33	17	-0.01263	-0.0007430	9.67667E-6	0.00311
PRIN34	17	-0.00125	-0.0000738	0.0000282	0.00531
PRIN35	17	0.00987	0.0005803	9.20908E-6	0.00303
PRIN36	17	-0.01328	-0.0007813	9.47743E-6	0.00308
PRIN37	17	-0.00964	-0.0005670	0.0000149	0.00385
PRIN38	17	-0.01023	-0.0006019	0.0000100	0.00317
PRIN39	17	-0.00188	-0.0001107	8.96132E-6	0.00299

Sully B

Variable	N	Sum	Mean	Variance	Std Dev
PRIN1	2	-0.0007197	-0.0003598	1.05875E-9	0.0000325
PRIN2	2	0.00529	0.00264	5.72277E-7	0.0007565

PRIN3	2	-0.01035	-0.00518	1.8843E-7	0.0004341
PRIN4	2	0.00883	0.00441	9.30454E-7	0.0009646
PRIN5	2	0.00858	0.00429	7.83555E-6	0.00280
PRIN6	2	-0.00296	-0.00148	0.0000705	0.00840
PRIN7	2	-0.01718	-0.00859	4.41781E-6	0.00210
PRIN8	2	-0.00131	-0.0006544	8.10507E-6	0.00285
PRIN9	2	0.00117	0.0005836	1.03757E-6	0.00102
PRIN10	2	-0.0005279	-0.0002640	0.0002110	0.01453
PRIN11	2	0.01690	0.00845	1.29253E-7	0.0003595
PRIN12	2	-0.00389	-0.00195	8.49822E-8	0.0002915
PRIN13	2	0.01511	0.00756	0.0000300	0.00548
PRIN14	2	0.00518	0.00259	0.0000731	0.00855
PRIN15	2	-0.0006392	-0.0003196	1.95865E-7	0.0004426
PRIN16	2	0.00227	0.00114	0.0000163	0.00404
PRIN17	2	0.01071	0.00535	0.0000511	0.00715
PRIN18	2	0.00112	0.0005580	1.64888E-6	0.00128
PRIN19	2	-0.01119	-0.00560	2.27907E-6	0.00151
PRIN20	2	0.00892	0.00446	1.22232E-6	0.00111
PRIN21	2	-0.00433	-0.00217	1.18816E-6	0.00109
PRIN22	2	0.0008437	0.0004219	0.0001032	0.01016
PRIN23	2	-0.0006489	-0.0003244	4.98894E-7	0.0007063
PRIN24	2	0.00201	0.00101	0.0000107	0.00327
PRIN25	2	0.00463	0.00232	6.94775E-7	0.0008335
PRIN26	2	-0.01017	-0.00508	1.05222E-6	0.00103
PRIN27	2	0.00184	0.0009209	1.43074E-9	0.0000378
PRIN28	2	0.00296	0.00148	0.0000419	0.00647
PRIN29	2	-0.00696	-0.00348	0.0000184	0.00428
PRIN30	2	0.00202	0.00101	0.0000126	0.00356
PRIN31	2	-0.00739	-0.00370	5.56035E-6	0.00236
PRIN32	2	0.00452	0.00226	7.21297E-6	0.00269
PRIN33	2	0.0006223	0.0003112	3.16363E-6	0.00178
PRIN34	2	-0.00189	-0.0009446	4.25669E-6	0.00206
PRIN35	2	0.00436	0.00218	9.4139E-10	0.0000307
PRIN36	2	0.00127	0.0006351	0.0000118	0.00344
PRIN37	2	0.0009972	0.0004986	4.0024E-8	0.0002001
PRIN38	2	0.00177	0.0008852	3.69554E-6	0.00192
PRIN39	2	-0.00350	-0.00175	0.0000126	0.00355

Sully D

Variable	N	Sum	Mean	Variance	Std Dev
PRIN1	18	0.00392	0.0002180	0.0001104	0.01051
PRIN2	18	0.10545	0.00586	0.0001218	0.01104
PRIN3	18	0.02695	0.00150	0.0001305	0.01142
PRIN4	18	-0.08911	-0.00495	0.0001174	0.01083
PRIN5	18	-0.08369	-0.00465	0.0000769	0.00877
PRIN6	18	-0.05100	-0.00283	0.0000631	0.00795
PRIN7	18	-0.06317	-0.00351	0.0000668	0.00817
PRIN8	18	-0.07516	-0.00418	0.0001221	0.01105
PRIN9	18	-0.02273	-0.00126	0.0000811	0.00901
PRIN10	18	0.00909	0.0005052	0.0000486	0.00697
PRIN11	18	-0.07090	-0.00394	0.0000345	0.00587
PRIN12	18	-0.00733	-0.0004072	0.0000690	0.00831
PRIN13	18	0.01816	0.00101	0.0000289	0.00537
PRIN14	18	0.07147	0.00397	0.0000715	0.00845
PRIN15	18	0.00254	0.0001413	0.0000637	0.00798
PRIN16	18	0.04165	0.00231	0.0000347	0.00589
PRIN17	18	-0.03115	-0.00173	0.0000500	0.00707
PRIN18	18	0.03757	0.00209	0.0000432	0.00657
PRIN19	18	0.01091	0.0006060	0.0000547	0.00739
PRIN20	18	0.03495	0.00194	0.0000371	0.00609
PRIN21	18	0.00891	0.0004949	0.0000160	0.00401
PRIN22	18	-0.01069	-0.0005939	0.0000264	0.00514
PRIN23	18	0.00306	0.0001697	0.0000206	0.00454
PRIN24	18	-0.01508	-0.0008379	0.0000209	0.00457
PRIN25	18	0.00270	0.0001500	0.0000233	0.00483
PRIN26	18	0.01907	0.00106	0.0000326	0.00571
PRIN27	18	-0.00110	-0.0000609	0.0000164	0.00405
PRIN28	18	-0.01602	-0.0008898	0.0000143	0.00378
PRIN29	18	-0.03187	-0.00177	0.0000270	0.00520
PRIN30	18	-0.00929	-0.0005159	0.0000122	0.00349
PRIN31	18	0.02069	0.00115	0.0000134	0.00367
PRIN32	18	-0.00328	-0.0001822	0.0000164	0.00405
PRIN33	18	-0.03537	-0.00196	0.0000208	0.00456
PRIN34	18	-0.00565	-0.0003141	0.0000217	0.00465
PRIN35	18	-0.01418	-0.0007880	0.0000118	0.00344
PRIN36	18	0.01113	0.0006186	0.0000205	0.00452

PRIN37	18	0.01007	0.0005595	0.0000134	0.00366
PRIN38	18	-0.02234	-0.00124	0.0000176	0.00420
PRIN39	18	0.02325	0.00129	0.0000142	0.00377

Sully E

Variable	N	Sum	Mean	Variance	Std Dev
PRIN1	21	0.03916	0.00186	0.0002397	0.01548
PRIN2	21	0.07063	0.00336	0.0001696	0.01302
PRIN3	21	-0.04754	-0.00226	0.0001223	0.01106
PRIN4	21	0.02307	0.00110	0.0001601	0.01265
PRIN5	21	-0.00761	-0.0003623	0.0000628	0.00793
PRIN6	21	-0.00674	-0.0003212	0.0000925	0.00962
PRIN7	21	-0.11857	-0.00565	0.0000809	0.00900
PRIN8	21	-0.13383	-0.00637	0.0000793	0.00890
PRIN9	21	-0.10228	-0.00487	0.0000316	0.00562
PRIN10	21	-0.00934	-0.0004448	0.0000460	0.00678
PRIN11	21	0.00561	0.0002672	0.0000482	0.00694
PRIN12	21	0.06277	0.00299	0.0000474	0.00689
PRIN13	21	-0.01228	-0.0005845	0.0000326	0.00571
PRIN14	21	0.06708	0.00319	0.0000359	0.00600
PRIN15	21	0.01838	0.0008753	0.0000532	0.00729
PRIN16	21	-0.02972	-0.00142	0.0000284	0.00533
PRIN17	21	0.05411	0.00258	0.0000170	0.00412
PRIN18	21	-0.04316	-0.00206	0.0000279	0.00529
PRIN19	21	-0.01622	-0.0007722	0.0000294	0.00542
PRIN20	21	-0.00316	-0.0001506	0.0000322	0.00568
PRIN21	21	0.03978	0.00189	0.0000356	0.00597
PRIN22	21	0.06750	0.00321	0.0000563	0.00750
PRIN23	21	-0.00425	-0.0002024	0.0000233	0.00483
PRIN24	21	-0.02249	-0.00107	0.0000239	0.00489
PRIN25	21	0.01878	0.0008942	0.0000291	0.00539
PRIN26	21	0.10159	0.00484	0.0000358	0.00598
PRIN27	21	-0.00610	-0.0002904	0.0000333	0.00577
PRIN28	21	-0.03832	-0.00182	0.0000265	0.00515
PRIN29	21	-0.08821	-0.00420	0.0000231	0.00481
PRIN30	21	-0.00564	-0.0002685	0.0000193	0.00440

PRIN31	21	-0.02111	-0.00101	8.10054E-6	0.00285
PRIN32	21	-0.00690	-0.0003284	0.0000144	0.00380
PRIN33	21	-0.01922	-0.0009151	5.77127E-6	0.00240
PRIN34	21	0.04450	0.00212	0.0000106	0.00325
PRIN35	21	0.02895	0.00138	0.0000115	0.00339
PRIN36	21	0.01918	0.0009132	0.0000115	0.00339
PRIN37	21	-0.03211	-0.00153	8.47601E-6	0.00291
PRIN38	21	0.00556	0.0002646	7.75797E-6	0.00279
PRIN39	21	-0.00472	-0.0002248	9.20446E-6	0.00303

VITA

Ashley Hyatt McKeown was born on August 22, 1969 in Atlanta, Georgia. She received a Bachelors of Arts in Anthropology from the University of North Carolina at Chapel Hill in 1991. In the fall of 1992 she matriculated at the University of Tennessee, Knoxville and graduated with a Masters of Arts in Anthropology in December of 1996. In the spring of 1996, Ashley became a Ph.D. student in the Department of Anthropology and was admitted to candidacy in the summer of 2000. The Ph.D. degree was conferred on December 16, 2000.

While at the University of Tennessee, Ashley engaged in teaching and research, co-authoring publications and producing various technical reports. She also authored and co-authored numerous papers and posters at professional conferences. In the spring of 1999, Ashley received the Chancellor's Award for Graduate Student Teaching.

On September 1, 2000, Ashley assumed a post-doctoral fellowship working jointly with the Association for the Preservation of Virginia Antiquities' Jamestown Rediscovery Project and the Physical Anthropology Department at the Smithsonian Institution.