A Taphonomic Analysis of Human Cremains from the Fox Hollow Farm Serial Homicide Site

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B.S., University of Indianapolis, 1998

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Human Biology in the Graduate School of the University of Indianapolis

December 2004

FORM B

Accepted by the faculty of the Graduate School, University of Indianapolis, in the partial fulfillment of the requirements for the Master of Science degree in

HUMAN BIOLOGY

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DEDICATION

To my parents, Bob and Angela, your constant support and love has helped me through so much. I am the person I am because of you.

To Anthony, my husband, you are my love and my partner and I thank you for helping me find my drive to complete this project.

To all who believed in me, thank you.

ACKNOWLEDGMENTS

I would like to take this time to acknowledge all the people who have given their time and expertise to this project and to whom I am grateful. I would first and foremost like to thank my committee. Dr. Stephen Nawrocki, you have believed in me since 1994 and I cannot express how many ways you have changed my life and my focus. I am honored to have you as my mentor and as a friend. Dr. Gregory Reinhardt, you took on this project late into its development and your commentary and guidance has been much appreciated. In addition to my committee, I would also like to recognize Dr. Christopher Schmidt. Dr. Schmidt, thank you for your guidance in the development of this project. You have been a quiet source of encouragement throughout my studies at the University of Indianapolis and I thank you.

I would also like to thank Dr. Dennis Dirkmaat for allowing me access to the comparative sample from his laboratory. To Idelle Ritterskamp, thank you for constant encouragement and most of all your friendship. To all the other graduate students I had the privilege to study with, thank you.

ABSTRACT

In June of 1996, the University of Indianapolis Archeology and Forensics Laboratory was asked to assist in the recovery of human remains from the Fox Hollow Farm, an 18-acre horse farm located north of Indianapolis in Westfield, Indiana. The remains of at least 11 homicide victims were discovered in two areas on the property. Scientific study of the remains from Fox Hollow Farm offers an opportunity to look at how numerous taphonomic processes affect a skeletal assemblage over a short period of time. The general goals of the present study are to ascertain the condition of the remains (fresh or dry) at the time of burning, to identify the taphonomic processes that may have contributed to the distribution of the remains, and to reconstruct assailant behaviors from the scientific data.

During the excavation of Area 1, 17 contiguous 2x2-meter grids were constructed. Two distinct datasets were derived from the remains in these grids. The first dataset includes all 5651 bone fragments from all grids, excluding complete bones and teeth. These fragments were counted and plotted to discern distribution patterns over the entire area, but no additional measurements or observations were taken on this assemblage.

The second dataset is a subset of the first. This dataset includes all of the complete bones and a random sample of fragments, exclusive of teeth. One hundred fragments were chosen from each of the 8 grids that produced more than 100 fragments. Altogether, a total of 800 fragments (8 grids x 100 fragments) and 133 complete bones make up the second dataset. All fragments from this set were assigned to one of 12 bone group categories. The maximum length of each fragment was measured to the nearest tenth of a millimeter. Each fragment was then scored as burned or unburned and scored for coloration. Fracturing was scored as the type

(transverse, longitudinal, curvilinear, or patina) that predominated on the body of the fragment. In addition, each fragment was assessed for warping and delamination. These characteristics were scored simply as present or absent.

In order to assess the degree to which the Area 1 sample was burned, the remains from Fox Hollow Farm were compared to five other burned specimens or collections whose degree of heat alteration had been defined through previous study. The comparative sample includes a commercial dog cremation, a commercial human cremation, a Late Archaic prehistoric cremation, and two recent forensic cases. These comparative samples were scored with the same criteria established for the Fox Hollow sample and comparisons were made between all assemblages. It seems that Fox Hollow is most similar to the commercial dog and commercial human cremations and least similar to the recent forensic cases or the prehistoric sample.

Fluvial transport was also addressed. The larger dataset from Fox Hollow was used to examine differential distribution of fragments across Area 1. The larger, less burned fragments were located uphill near the top of the grid system, while the smaller, more heavily burned fragments were located downhill at the bottom of the grid system. While assailant behaviors and carnivore activities cannot be ruled out as contributors to the distribution of remains in Area 1, it seems that flowing water was the major source of dispersal for the remains.

This study suggests that fragment size is crucial when looking at heavily-burned assemblages. Traits used to determine the pre-burning state of the bones (fresh or dry) may be easily masked by small fragment size. However, at least some of the remains from Fox Hollow show characteristics consistent with bone that was burned with soft tissues and fats still present. Other evidence indicates that some victims were allowed to decompose before burning.

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CHAPTER 1: INTRODUCTION

Taphonomy is the scientific reconstruction of events that occur during and following the death of an organism. In fact, taphonomy literally means the "laws of burial" (Efremov 1940). Such reconstruction has historically included information gleaned from the recovery and depositional context of the remains, the overall preservation of the remains, an assessment of any type of modification to the remains, and an assessment of the interval from the death and deposition of the organism to the time of discovery of the remains (Haglund and Sorg 1997:14).

Taphonomy was born out of investigations of ancient organisms and is most closely associated with archeology, paleoanthropology, and paleontology. In these fields, taphonomy is applied to reconstruct the circumstances of the life and death of an organism. Taphonomy has now found a niche in the investigation of the recent past as forensic anthropologists have begun to apply taphonomy to contemporary death investigations.

Haglund and Sorg (1997) outline four major differences between the application of taphonomy in an archeological context and a forensic context. The first major difference is the time frame involved. Applications of taphonomy in forensic science deal more with the time immediately surrounding the death of an organism, while more classical applications of taphonomy are used in reconstructing the entire life history of the organism. Second, forensics has broadened the focus of taphonomy to include observations of soft tissues, which are used to estimate the postmortem interval. Third, unlike archeology and paleoanthropology, the focus of forensic anthropology is on the individual rather than on the population or species. Fourth, the forensic anthropologist is forced to conform to the regulations of the medicolegal system, something rarely of concern to archeologists.

Fox Hollow Farm

In June of 1996, the University of Indianapolis Archeology and Forensics Laboratory was asked to assist in the recovery of human remains from the Fox Hollow Farm, an 18-acre horse farm located north of Indianapolis in Westfield, Hamilton County, Indiana. The remains of at least 11 homicide victims were discovered in two areas on the property: a wooded area directly behind the main dwelling (Area 1), and within a creek bed on the western border of the property (Area 3) (Nawrocki et al. n.d.).

The condition of the remains varied greatly between the two areas. The majority excavated from Area 1 were burned, commingled, and heavily fragmented. Genetic testing indicated that at least five individuals are present in the Area 1 sample of remains, three of whom were positively identified via DNA analysis and/or dental analysis. All three individuals were reported missing in the summer of 1994 and therefore had been dead approximately 2 years at the time of discovery.

With the exception of a few lightly burned bones, the majority of remains from Area 3 were complete and unburned. Genetic testing of the remains from this area indicated the presence of at least six individuals, four of whom were positively identified via DNA analysis and/or dental analysis. The four identified individuals were reported missing in 1993 and therefore had decomposed over a 3-year period. One week was spent excavating the remains in each of the two areas. In April of 1997 a one-day field survey was conducted in order to determine if additional excavation was needed. As a result of the survey, a third week of work was conducted in May 1997 in Area 3 (Nawrocki et al. n.d.).

Prior research conducted on the Fox Hollow skeletal assemblage has focused on the osteology, archeology, or taphonomy for the entire site or for Area 3 (Baker 2000; Nawrocki and

Baker 2001; Nawrocki et al. 1998; Nawrocki et al. n.d.). The proposed study focuses on the taphonomy of Area 1, which presented both an archeological and a logistical challenge for the investigators. The area is moderately wooded, and a progressively-sloping drainage channel spans the length of Area 1 from north to south (Figure 1). The channel provides drainage for the gutter system of the main residence and descends over 3 meters in elevation to its southernmost point. While the burning event seems to have taken place in a centralized spot, the remains were distributed over 80 square meters of sloping forest floor (Nawrocki et al. n.d.).

The general goals of the present study are:

(1) to ascertain the condition of the remains (fresh or dry) at the time of the burning;

(2) to identify the taphonomic processes that may have contributed to the distribution of remains over Area 1; and

(3) to reconstruct assailant behaviors from the scientific data, if possible.

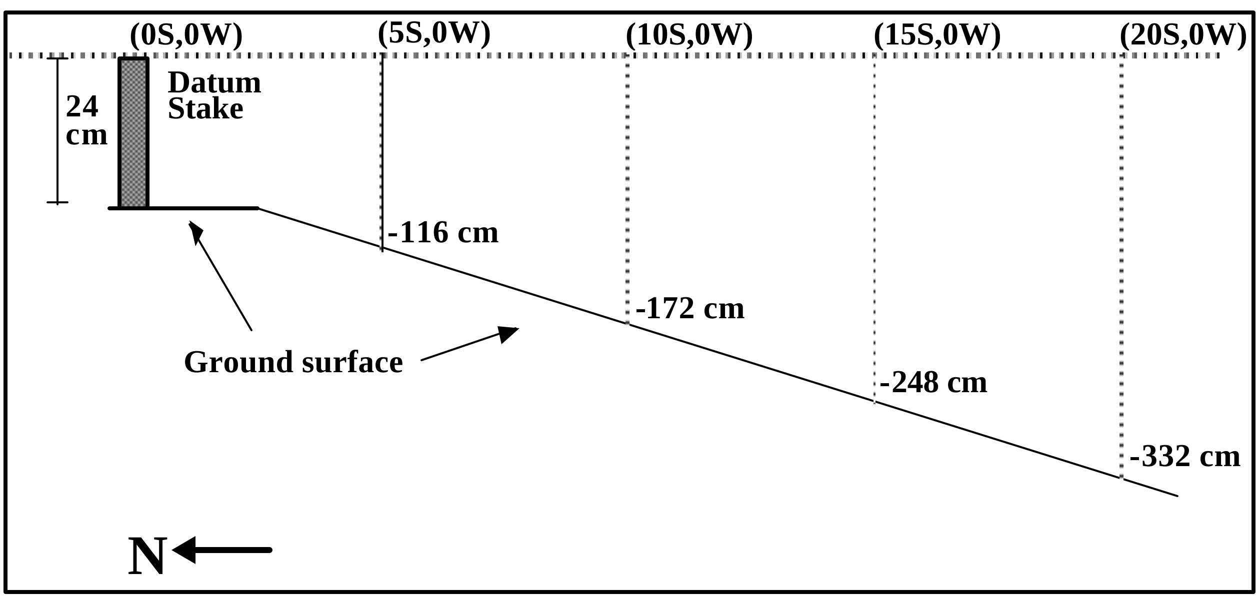

FIGURE 1. The slope in Area 1 of Fox Hollow Farm. Numbers in parentheses are grid markers that are 5 m apart (after Nawrocki et al. n.d.).

Statistical analysis of the cremains will attempt to reject the following null hypotheses: (1) Fox Hollow cremains are not significantly different from other forensic, prehistoric, or commercial cremains, and (2) there is a random distribution of remains within the grid system of Area 1.

Unfortunately, little is known about the events that led to the deaths and eventual disposal of these individuals. The assailant in this case committed suicide shortly after the investigation at Fox Hollow Farm began, leaving the investigators to reconstruct the details (Weinstein and Wilson 1998). While careful examination of this particular assemblage may provide information that can assist in the closure of the case, scientific study also offers an opportunity to look at how numerous taphonomic processes affect a skeletal assemblage over a short period of time.

Chapter 2 of this thesis presents relevant background on bone structure, the characteristics of burned remains, and fluvial transport. Chapter 3 details the methods used for sample analysis. Chapter 4 provides the results of the analysis of burning in the six samples and Chapter 5 discusses the fluvial transport of remains in Area 1. Chapter 6 presents the conclusions of the study and makes suggestions for future research with burned bone.

CHAPTER 2: BURNING AND FLUVIAL TRANSPORT

Burning

In recent years forensic anthropologists have been called upon to use their expertise in the reconstruction of remains that have been altered by fire. Such involvement has included cases of criminal misconduct (Eckert et al. 1988; Dirkmaat 1998; Johanson and Saldeen 1969; Sweet and Sweet 1995), mass disasters (Martin-de las Heras et al. 1999; Owsley et al. 1995), and commingling of remains in modern crematory processing (Kennedy 1996). In addition to reconstructing burned remains in the laboratory, the forensic anthropologist is also called upon to assist in recovering burned remains at the crime scene. Many forensic anthropologists are trained in standard archeological methods. It has been argued, especially in the case of burned remains, that early entrance of a trained forensic anthropologist will lead to a more comprehensive recovery that includes important contextual data for taphonomic reconstruction (Dirkmaat and Adovasio 1997:48; Dirkmaat 1998).

In much of the literature, the terms "burned" and "cremated" are used interchangeably to describe bone that has been exposed to heat. Ubelaker (1999:167) defines cremation as "the act of burning a body or the remnants of a burned individual". A complete reduction of human remains is accomplished only when they are exposed to high temperatures for extended periods of time. The remnants of a complete reduction can be described as highly fragile, fragmented, commingled, and usually white/gray in color. Fragment size in such cases is usually very small, which is a function of the fragile condition of the remains and also of additional processing that may have occurred, such as raking, stoking, or pulverization (McKinley 1994). Cases of such thorough reduction are rare in accidental burnings but can be seen in modern day cremations at funeral homes and in ancient mortuary practices (Baby 1954; Binford 1963; Eckert et al. 1988; Ubelaker 1999:36).

Remains that have been exposed to heat in accidents, homicides, or suicides often display characteristics that are distinguishable from those created by intentional reduction. In the former, the spatial distribution of the bones on recovery roughly conforms to their proper anatomical positions, the remains are incompletely incinerated, and soft tissue is often present (Dirkmaat 1998; Eckert et al. 1988; Martin-de las Heras et al. 1999; Owsley et al. 1995).

I feel that the appropriate definition of "cremation" is *the purposeful reduction of human remains via burning and post-burn processing*. This definition makes a distinction between accidental or superficial burning and the intentional reduction of human remains. It is the general goal of this study to determine the degree to which the Fox Hollow remains were exposed to heat and whether it is appropriate to classify the burning event at Fox Hollow as cremation or simply burning.

For the forensic anthropologist, identifying heat-exposed human remains presents a challenge. A working knowledge of the characteristic pattern of destruction that fire has on bone facilitates analysis of the remains. Coloration, fracture pattern, warping, and shrinkage can all give distinct clues as to the manner in which the bone was burned, if the bone was covered in flesh or not, to what degree the bone was burned, and any evidence of perimortem trauma (Herrman et al. 1999; Shipman et al. 1984; Buikstra and Swegle 1989; Correia 1997; Correia and Beattie 2001).

Bone Composition and Mechanics

Bone is a complex and dynamic connective tissue. Not unlike other connective tissues, bone is composed of cells and an extracellular matrix. However, it is the high concentration of inorganic minerals in the extracellular matrix that distinguishes bone from other connective tissues (Nordin and Frankel 1989:3). Bone is said to be "biphasic" because its matrix has two different components. The inorganic component of the matrix is a calcium phosphate salt (hydroxyapatite) and comprises approximately 65 percent of the dry weight of bone. It provides bone with rigidity and compressive strength. The organic component of the matrix consists mostly of the protein collagen and composes the other 35 percent of bone weight. It provides bone tissue with elastic strength. Together, these two components are stronger than each material is alone (Currey 1984:24-25; Davis 1987:48; Nordin and Frankel 1989:3).

Applying a stress or a load to a structure can cause a change in the dimensions of that structure. When a load is applied, the change in the structure's dimensions can be plotted on a load-deformation curve (see Figure 2). This curve can also depict the extent to which bone may be deformed (strained) under continued loading (stress) (Nordin and Frankel 1989:6).
The first portion of this curve is known as the elastic region. During this phase of loading, bone has the capacity to return to its original shape if the stress is removed. If the load continues then the bone tissue will reach its yield point, or the point at which the outside fibers of the bone begin to yield under the increasing load. After the yield point is reached the structure enters into the plastic region of the curve. In this portion of the curve bone can no longer return to its original shape and some permanent deformation occurs. If the load continues the structure will fail, and the bone fractures (Nordin and Frankel 1989:7).

Bone that has been burned has much less collagen in it and therefore is much more brittle than unburned bone. When stressed, the bone will reach its yield point and but the plastic region is nearly nonexistent. As a result, burned bone will act more like glass, reaching its failure point more quickly and with little or no permanent deformation.

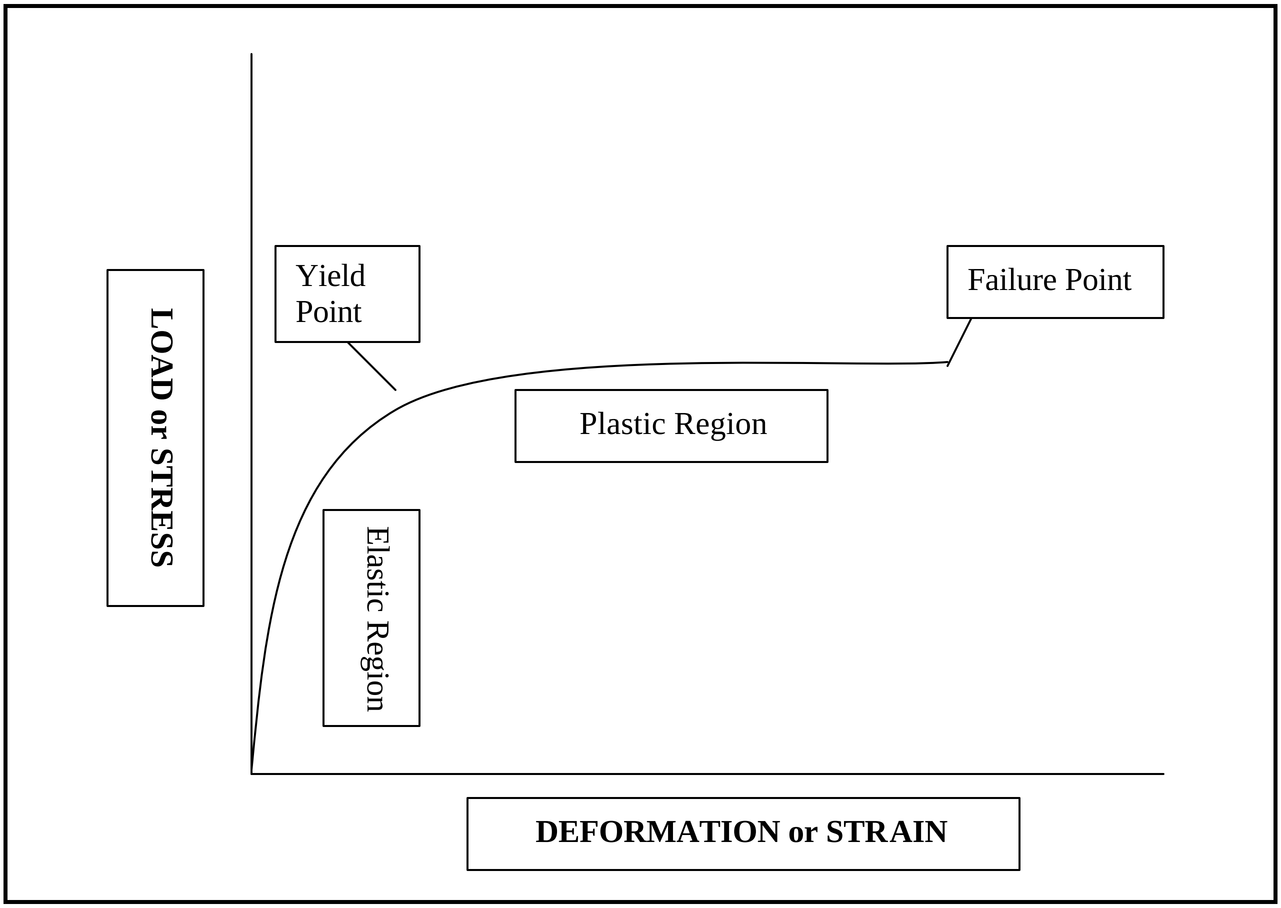

FIGURE 2. Load deformation curve for bone tissue (after Nordin and Frankel 1989:6).

Shipman et al. (1984) believe that heated bone goes through progressive stages of stress. *Dehydration* occurs when hydroxyl bonds are broken in the hydroxyapatite, and water molecules bound to the collagen are removed. This process causes extensive cracking, checking, and warping. *Decomposition* of the organic component of bone occurs next, between 360 and 525^{o} C, resulting in the complete loss of collagen. In conjunction with this heat range, there is a progressive change in bone color. At temperatures exceeding 625^{o} C, the authors noted a *change in the size of the hydroxyapatite crystals***.** In the past, this increase has been attributed to the inversion of hydroxyapatite crystals into tricalcium phosphate. However, the work of Shipman et al. (1984) suggests that larger hydroxyapatite crystals are formed, not a new substance. *Fusion* of the hydroxyapatite crystals occurs at temperatures exceeding 800^{o} C, rendering the bone friable and more susceptible to fragmentation (Stiner et al 1995).

Coloration

As a result of its biphasic construction, bone goes through characteristic color changes depending on the duration of the heat exposure, the fire's temperature, and the presence of soft tissues (Binford 1963; Buikstra and Swegle 1989; Correia 1997). Based on the results derived from studies by Baby (1954) and Binford (1963), Shipman et al. (1984) classified the color range seen in burned bone into four categories. The first is unburned, bearing no change in coloration. The second is non-incinerated smoked or blackened around the edges. In this stage, the bone has become darker. The third category is incompletely incinerated or black/brown. In this stage, the bone has been altered by the heat and has taken on a charcoal-like color and texture. The final category is incinerated or calcined; the bone is blue-gray to white in color and has taken on a chalky texture. At this stage there is total degradation of the organic component of bone. A white coloration indicates a longer exposure to higher temperature than blue-gray does (Ubelaker 1999:36). Dunlop (1978) has also documented a rare range of colors including pink, green, and yellow. These hues seem to be taken on by the bone as an effect of high concentrations of certain metals, such as zinc and copper, in or around the bone at the time of burning.

In addition to predictable heat-related color changes, the distribution of color may indicate the position of the body during burning. For example, Binford (1963) describes atypical cremations from the prehistoric Pomranky and Andrews sites in Michigan. At both sites he documented that the bone of the elbow area of burned persons was more or less untouched by the fire. This struck the investigator as unusual because the elbow is not protected by thick muscle and should therefore easily become calcined in a fire. Binford speculates that the arms of the deceased were bound and the body placed on the funeral pyre in such a way that it protected this area from complete incineration. Therefore, the overall pattern of burning can potentially reveal important information about the position and/or condition of the decedent during the burning event.

While these clues are useful in ancient settings, they can be just as informative in a forensic context. The distinct coloration differences associated with length of exposure and temperature can indicate what body parts of the victim were most exposed to the heat source (Eckert et al. 1988). The average wood-fueled fire ranges from 400^{o} to 700^{o} C (Shipman et al. 1984). While this temperature range is found within the flames, the heat is not necessarily evenly distributed. For example, the center of the fire may be much hotter than its peripheries. If a victim is added to a typically heterogeneous fire, uneven heating can lead to differential burning of the body. Therefore, an investigator may find the entire range of heat-induced coloration on a single victim (Eckert et al. 1984).

Fracturing, Shrinkage, and Warpage

Fractures occur when stress applied to an area exceeds the tensile strength of the material in that area. Heating bone results in the dehydration of collagen, causing bone to lose its elasticity and tensile strength. As a result, the bone's structural integrity is compromised. Heated bone cannot accommodate the stresses induced by shrinkage, caused by the fusion of the hydroxyapatite crystals, and therefore the material fails or fractures (Bradtmiller and Buikstra 1984; Herrman and Bennett 1999).

Fracturing can offer some limited evidence regarding the condition of the remains prior to the cremation event. Most commonly, the fracture pattern is used to determine whether bones were burned with a considerable amount of soft tissue and fats still present (fleshed/green state) or whether they burned essentially devoid of soft tissue and fats (dry state) (Baby 1954; Binford 1963; Buikstra and Swegle 1989; Thurman and Willmore 1980). However, interpreting fracture patterns (length, configuration, distribution, and depth) is a source of debate between researchers embroiled in this topic.

Herrman and Bennett (1999) summarize five distinct fracturing patterns in burned bone. The first pattern is classified as *longitudinal.* This particular fracture travels with the long axis of the bone and varies in its depth. The second pattern is a *curved transverse,* or *thumbnail, fracture*. Such fractures usually appear in a stacked fashion, one curvilinear fracture atop another, and have been associated with the shrinkage of soft tissue during burning. The third pattern is the *straight transverse*, or *step fracture*. This fracture usually extends from the edges of the longitudinal fracture against the grain of the bone. The fourth pattern is *patina*. This fracturing pattern usually affects the outer layers of cortical bone and is typically found on the epiphyses. Its appearance has been likened to that of an aged, cracked oil painting. The final pattern is *delamination*, a peeling or flaking of cortical bone away from the underlying spongy bone. Delamination occurs most commonly in the cranial bones and at the epiphyses.

In addition to fracturing, warpage and shrinkage are visible signs of bone deformation that result from burning. Warpage affects the visual appearance of bone and results from stresses induced by the heating process. As the organic component burns off, the bone tissue loses its tensile strength and therefore begins to deform. In some cases, bone can recover if the stress is removed; however, if the stress remains the bone tissue will deform until failure (Corriea 1997;

Herrman and Bennett 1999). Shrinkage, on the other hand, is attributed to the fusion of hydroxyapatite crystals, and, as a result, bone length and width are reduced (Bradtmiller and Buikstra 1984). There is little consensus regarding the rates of shrinkage. The published rates of shrinkage vary from 0% to 25% at approximately 800^{o} C (Bradtmiller and Buikstra 1984; Buikstra and Swegle 1989; Correia 1997; Herrman and Bennett 1999; Shipman et al. 1985; Ubelaker 1999:35).

While there are no standards in place to help researchers clearly distinguish between wet/fleshed cremations and dry cremations, consideration of all the known characteristics in concert may allow some inferences regarding the state of remains before burning. In general, it seems that remains burned in a wet/fleshed state exhibit varying color patterns, deep fracturing, pronounced warpage, and delamination. Conversely, bones burned in the dry state usually express very little color variation on the outer surface, superficial fracturing, and little, if any, warpage (Buikstra and Swegle 1989; Corriea 1997).

Fluvial Transport

Dispersal patterns of artifacts and skeletal remains at a site can yield clues about cultural and postmortem processes. Reinhardt (1993) states that understanding the context of a site depends on two observations: (1) the distribution of the significant material, and (2) possible transformation processes (i.e., erosion or transport) that could have affected the distribution of materials throughout the site. The interpretation of context is the cornerstone of archaeological, paleontological, and forensic site analyses. Without context, sites can yield little reliable information on the processes that led to their formation.

There are numerous dispersal processes (environmental, cultural, and animal) that affect how materials are found at sites. This particular study will emphasize the effects of flowing water on burned skeletal remains. The movement of an object by water is known as "fluvial transport". Studies of fluvial transport have traditionally been rooted in paleontology (Behrensmeyer 1982; Shotwell 1955) and archaeology (Petragalia and Potts 1994; Reinhardt 1993; Turnbaugh 1978). However, the importance of flowing water on the dispersal of human remains in forensic contexts has also been examined recently (Baker 2000; Davis 1986; Giertsen and Morild 1989; Haglund et al. 1990; Nawrocki et al. 1997; Nawrocki et al. 1998; Nawrocki and Baker 2002; Nawrocki et al. n.d.). Bones differ in their potential for fluvial transport. A bone's size, density, and shape are the most important factors in determining its hydraulic behavior (Shipman 1981).

Flume studies. Some authors (Boaz and Behrensmeyer 1976; Voorhies 1969) have attempted to recreate natural fluvial process in the laboratory. Voorhies (1969) conducted a flume study in which he noted different dispersal patterns for various types of coyote and sheep bones. Voorhies observed that the skeletal material sorted into three separate transport groups and that these groups might be used to deduce the degree of transportation and sorting in other fossil assemblages. Voorhies' groups were (1) those bones that were immediately moved by low-velocity currents (Group I), (2) those removed gradually by moderate currents (Group II), and (3) a lag group moved only by high velocity currents (Group III).

Boaz and Behrensmeyer (1976) have shown that these rules of transport also apply to human skeletal material. They conducted a flume experiment using 35 elements, including intact crania, fragmentary long bones, and isolated teeth. Like Voorhies (1969), they discovered that there is a group of skeletal remains that do not move at all within the flume and another group of skeletal remains that move a significant distance. They labeled these two groups the “lag group” and the “transport group,” respectively. The *lag group* was comprised of fragmented long bones, individual teeth, and cranial fragments. These typically flat or small skeletal parts lack the bony processes to project them out of the lower, slower currents near the bed of the flume or stream. Also, these skeletal fragments tend to be dense for their overall size. In concert, these characteristics prevent such fragments from being swept up in currents, and therefore they are more likely to be deposited near the point of entry into the water source (Boaz and Behrensmeyer 1976).

The *transport group* consisted of complete crania, intact foot bones, a proximal ulna and radius, and an intact thoracic vertebra. Elongated bones that are circular in cross-section and less dense for their overall surface area characterize this group. These remains possess the bony projections that can make them susceptible to the faster-moving currents. They can be expected to travel greater distances from the primary point of entry (Boaz and Behrensmeyer 1976).

Boaz and Behrensmeyer (1976) note that experimental factors may have led to some discrepancies between their and Voorhies' (1969) results. Firstly, Voorhies used animal bones, which differ from human bones in shape and density. Secondly, the majority of skeletal remains used by Boaz and Behrensmeyer were fragmentary, while those used in Voorhies' flume experiment were complete. Finally, Voorhies' flume conditions (namely the bottom substrate) were not the same as those conditions in Boaz and Behrensmeyer's flume.

As of yet, none have studied the fluvial transport of burned remains. The remains from Fox Hollow Farm were subjected to fluvial transport via rainwater in the drainage channel from the gutter system of the residence. Can it be expected that the remains at Fox Hollow mirror the "lag" and "transport" groups that Boaz and Behrensmeyer (1976) defined based on their flume experiments? Or are there other factors, such as degree of burning and fragment length, that affected the transport characteristics of the cremains?

CHAPTER 3: THE STUDY SAMPLE AND METHODS

One of the main goals of this study is to determine whether the assailant in the Fox Hollow case purposefully reduced the victims' remains via burning or, without attention to a complete reduction, set the remains ablaze in the hopes that the fire would consume the remains enough to hide the crime. In order to determine if the remains from Fox Hollow Farm can be classified as a deliberate cremation, it is necessary to compare these remains to other collections that have been altered by fire. In addition to determining the degree to which the Fox Hollow sample was reduced or transported, it is also a goal of this study to determine distribution patterns of fragments within the grid system of Area 1.

Sampling Process

During excavation of the Fox Hollow Site, 17 continuous 2x2-meter grids were established, and a grid-specific provenience is available for each fragment (Figure 3). Two distinct datasets are available for the Fox Hollow assemblage. The first dataset includes all 5651 bone fragments from Area 1, excluding complete bones and teeth. These fragments were counted and plotted to discern distribution patterns over the entire area, but no additional measurements or observations were taken on this complete sample

The second dataset is a subset of the first, a random sample of fragments from each grid. To standardize the sample, 100 fragments were chosen per grid, and these fragments were subjected to more thorough analysis that would not have been possible for every fragment in the assemblage. No fragments were chosen from the 10 grids that produced less than 100 fragments. The author obtained a 2.5'x 2.5' piece of paper and a grid of 3"x3" squares was drawn on it and

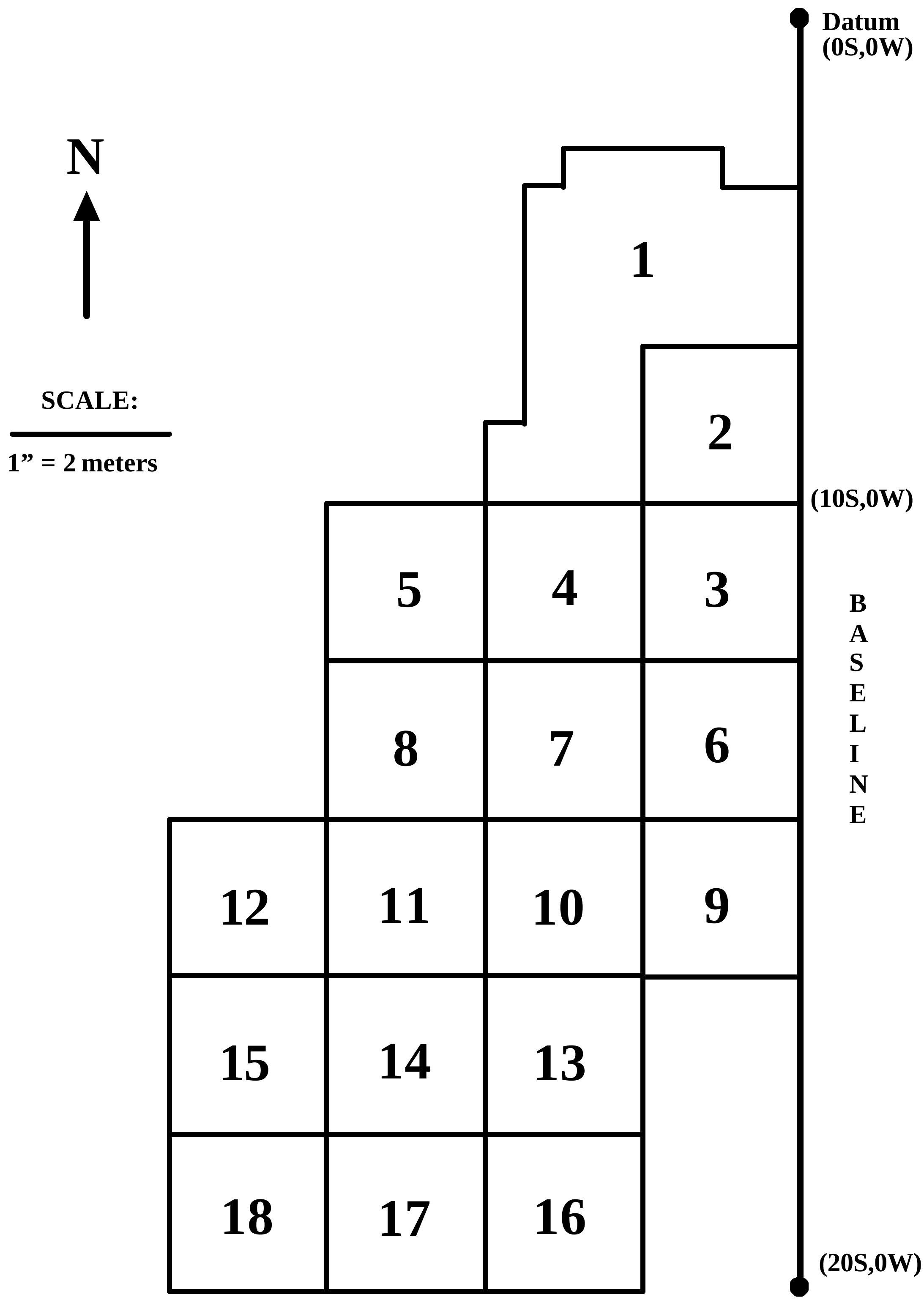

FIGURE 3. Area 1 grid plan (after Nawrocki et al. n.d.).

numbered from 00 to 99. The remains from each qualifying grid were spread over the entire table and then, using a table of random numbers, 100 fragments (excluding tooth fragments) were selected at random.

Grid 1 was originally excavated as an irregular 11.5 m^2 grid (Figure 3). Only 7.5 m^2 of Grid 1 contained bone fragments. It made sense to separate these 7.5 m^2 into two parts, Grid 1A and Grid 1B, measuring 4 square meters and 3.5 square meters, respectively, each with a subsample of 100 fragments. Altogether, a total of 800 fragments (8 grids x 100 fragments) were scored. However, 8 of the fragments were later removed from the study sample because it was determined that they were likely broken by carnivore chewing and not by burning. Therefore, the final count for the second data set is 792 fragments. In addition, all 133 complete bones from Area 1 (excluding complete teeth) were analyzed and included in the second dataset.

Methods

All fragments from the second dataset at Fox Hollow Farm were gently cleaned with a dry soft toothbrush to remove any residual debris. The maximum length of each fragment was measured to the nearest tenth of a millimeter. Maximum length was chosen because it is an easily accessible measurement and is indicative of the overall size of the fragment. Furthermore, fragment length can reflect the degree of burning as well as the degree of mechanical alteration caused by post-burning transport. Complete bones were not measured, because the obtained values would reflect physiological adaptations rather than taphonomic alterations.

All fragments and complete bones in the sample were assigned to one of twelve bone categories based on identifiable morphology (Table 1). These bone categories will be utilized to determine if there is differential distribution of particular skeletal elements over Area 1.

TABLE 1. Bone category assignments.

0:	cranium and mandible
1:	vertebrae
2:	thorax (ribs and sternum)
3:	clavicle
4:	scapula
5:	upper extremity (humerus, radius, ulna)
6:	hand
7:	pelvis and sacrum
8:	lower extremity (femur, tibia, fibula, patella)
9:	foot
10:	specific bone unknown, long bone or cortical bone fragment
11:	specific bone unknown, trabecular bone fragment

Each fragment was scored as burned or unburned. In addition, the color of the outer surface (or ectocranial surface, in the case of vault bone) of each fragment was scored based on a coding system established by Greene and Schmidt (2000), which is derived from Buikstra and Ubelaker (1994). This system condenses the four color categories used by Shipman et al. (1985) into three color categories: unburned, black/brown (lightly burned), and blue-gray/white (heavily burned). This simplified classification system reduces the incidence of intra-observer error that is often experienced when patterns are scored with more complex systems (Greene and Schmidt 2000).

The inner (or endocranial) surface of each fragment was also scored. The term "inner surface" is used here to indicate both the exposed medullary (or dipolic) surface of the cortex as well as the endocranial cortical surface of intact cranial vault bone. The inner surface was scored in the same way as the outer surface. Only 7 of the 792 fragments from Fox Hollow could not be scored on the inner surface. The Potter County sample had 31 bone fragments that could not be scored for inner surface color and the commercial dog cremation had one fragment that could not be scored.

Other characteristics of burned bone were scored. Fracturing was scored as the type (transverse, longitudinal, curvilinear, patina, or delamination) that predominated on the outer surface of the body of the fragment. Step fracturing was scored as a transverse fracture. Recall that transverse fractures typically extend from the edges of longitudinal fractures, creating a step-like configuration.

Fracture lines were present not only on the bodies of the fragments but also along their edges. However, only fractures that occurred on the body (outer surface) of the fragment were scored, as fractures to a fragment's edge can be caused by post-burning processes. In addition, each fragment was assessed for warping, scored as simply present or absent.

The Comparative Sample

The remains from Fox Hollow Farm were compared to five other burned specimens or collections whose degree of heat alteration had been defined through previous study. Because of how they had been curated, each of the comparative samples offered challenges to the sampling process. In order to obtain a representative sample and to work around the needs of the curators of the remains, it was sometimes necessary to modify my strategy for data collection. The comparative sample includes a commercial dog cremation, a commercial human cremation, a Late Archaic prehistoric cremation, and two recent forensic cases.

Lawrence County, Pennsylvania. In June of 1987, the Pennsylvania State Police contacted Dr. Dennis Dirkmaat (now of Mercyhurst College in Erie, PA) to survey the site of a potential homicide in Slippery Rock Township, Lawrence County, Pennsylvania. The remains of a 16 year-old girl, missing since 1965, were allegedly buried in the burned and abandoned house on the property. An informant told police that the body was burned in the home after her death and then sometime after the initial burning the assailant returned to the property and set the house ablaze.

The site was covered with a large quantity of debris. The landowner had bulldozed dirt and burned debris into the open foundation where the house had stood. Dr. Dirkmaat and his team used a backhoe to remove the 3 to 4 feet of overburden. At approximately 1.5 feet above the basement floor of the structure, heavy excavation was replaced by trowel and shovel work. Bone was discovered in the center of the structure. Due to the poor condition of the skeletal material, the fill from this area was taken back to the laboratory in its entirety.

Dr. Dirkmaat and his team separated the bones into identifiable and unidentifiable fragments. In all, the Lawrence County specimen includes over 2300 bone fragments. Dr. Dirkmaat notes in his 1987 report to the Pennsylvania State Police that none of the bones recovered at the site are complete, most are extensively warped due to the intensity of the heat, and that most are blue-grey to white in color. The large concentration of remains in one area suggested that the remains were not scattered in the bulldozing of the dwelling.

I examined the Lawrence County remains at Mercyhurst College in September of 2002. They had been segregated into plastic trays and plastic bags with labels identifying bone category. In order to maintain the integrity of this curation system, it was decided that all fragments that had an identifying label would be scored (n = 184). The remaining unidentified skeletal material had been divided into 10 plastic trays. I randomly sampled 10 fragments from 7 of these trays (n = 70) using the same methods employed in the Fox Hollow data collection. Two of the plastic trays were excluded because they did not contain at least ten fragments. Another tray was excluded because all of the fragments were fused to pieces of melted plastic and glass. It was impossible to discern the edges of the fragments for measurements or to fully appreciate all of the characteristics of the burn patterns. In all, 254 fragments were examined from this site. All were measured and categorized by bone type. In addition, each fragment was scored for color, fracture pattern, warpage, and delamination.

Potter County, Pennsylvania. In 1995, Dr. Dirkmaat was called to investigate burned remains that were discovered in Potter County, Pennsylvania. Skeletal elements representing the entire body were present for study. It was determined that the remains were of a gracile male between the ages of 20 and 50 years. There was no sign of perimortem trauma or evidence of the manner of death. Dr. Dirkmaat (personal communication, 2002) speculates that the individual was the victim of an accidental fire started by a wood-burning stove.

The remains are fragmentary and friable. The color (black through blue-grey to white) is indicative of extensive heat alteration. There are a number of large and identifiable elements including a portion of the right shoulder girdle and a portion the thoracic spine, both encased in dried soft tissue.

I examined the Potter County remains in September of 2002. They had already been organized into plastic bags. Unlike the Lawrence County remains, this specimen contained many large diagnostic fragments. As with the Lawrence County case, all diagnostic fragments were scored (n = 160). In addition, there were six bags containing unidentified remains. Ten fragments were randomly chosen from each bag using the grid of random numbers. In all, 220 fragments were included in this sample and all were measured and categorized by bone type. In addition, each fragment was scored for color, fracture pattern, warpage, and delamination.

The Jerger Site. The Jerger site, located in the White River Valley in Daviess County, Indiana, is an Early Archaic mortuary site. Local residents discovered this site in a cultivated field, finding cremated human bone, projectile points, and cultural material. Approximately five years after it was initially located, Curtis Tomak of the Indiana Department of Transportation was called in to evaluate the site. By this time the debris field had grown to approximately 6000 square feet. Tomak and his crew spent 23 days excavating the site (Tomak 1979).

An extensive assemblage of materials was found at the Jerger Site and many of these are still undergoing examination (Greene and Schmidt 2000). Many of the skeletal remains are currently curated at the University of Indianapolis. The cremated bone is highly fragmented and commingled, containing both human and animal bone. The fragments range from unburned to completely calcined.

The remains used in the current study were previously cleaned and bagged by students at the University of Indianapolis and are associated with a plow zone sample. According to Dr. Christopher Schmidt (personal communication, 2003), the bag of remains I examined was a representative sample of the human remains found at the site. One hundred fragments were randomly chosen from this bag, all of which were measured and categorized by bone type. In addition, each fragment was scored for color, fracture pattern, warpage, and delamination.

Commercial dog cremation. This specimen, of *Canis familiaris*, was commercially cremated in New York State but not mechanically pulverized. These remains were donated to the University of Indianapolis for curation and have remained in the possession of the Archeology and Forensics Laboratory in their original styrofoam shipping box. The fragments are extensively burned, and most are heavily calcined. The fragments are fragile and have broken over the years. There are a few pieces of other debris throughout, including slag.

The remains from this specimen were spread over the random number grid. One hundred fragments were chosen and all were measured and categorized by bone type. In addition, each fragment was scored for color, fracture pattern, warpage, and delamination.

Commercial human cremation. These remains were cremated and mechanically pulverized by an independent Indiana crematorium in 1987 and were returned to the funeral director for interment. The specimen was later donated to the University of Indianapolis Archeology and Forensics Laboratory for curation and study. The remains arrived at the laboratory in a cylindrical metal can.

According to the description provided with the remains, the individual was an adult male 63 years of age and approximately 190 pounds at the time of death. The remains are highly fragmented and extensively altered by the heat, with the color ranging from blue/gray to white. In addition, yellow and pink colors are observed in this sample. Prior to the current study, the remains had been sorted using geological sieves. Three separate fractions were obtained: ash (passed through a #20 sieve), small fragments (caught by the #20 sieve), and large fragments (caught by a #6 sieve).

Only the fragments caught by the #6 geological sieve were included in this study. The smaller fractions were not examined due to their extremely small size (fragments of this size were not collected at Fox Hollow). Like the dog cremation, the remains from this specimen were spread over the random number grid. One hundred fragments were chosen and all were measured and categorized by bone type. In addition, each fragment was scored for color, fracture pattern, warpage, and delamination.

Statistical Analysis

The data collected from Fox Hollow were compared to those taken from the other forensic, prehistoric, and commercial cremations. The analysis included both qualitative and quantitative comparisons based on fragment measurements, color, fracture pattern, texture, and warpage. A series of Student's t-tests was employed to check for differences in mean fragment length among the samples. Within the Fox Hollow sample, chi-squared tests were employed to test for non-random distributions of fragment types across the site. Analysis of Variance (ANOVA) was also employed to determine if there is a significant difference in fragment length between grids.

CHAPTER 4: RESULTS

Descriptions of the Individual Samples

This section will discuss the results obtained from the data collected from each of the six samples, presented individually below. Raw fragment counts and percentages for each bone category for each site are given in Tables 2 and 3.

Fox Hollow. The majority of the fragments from Fox Hollow were classified as unidentified cortical and trabecular bone (category numbers 10 and 11). These two bone categories composed nearly 70% of the entire sample (Table 3). The next most common bone category (#0) is cranial and mandibular elements, at 9%. Vertebral, rib/sternal, and upper extremity categories (numbers 1, 2 and 5) range from 2 to 5%. The least common bone categories, clavicle (#3) and pelvis (#7), weigh in at 1% each. The Fox Hollow sample also included 133 complete bones. The majority (97%) of these were classified either as hand bones (#6, 59%) or as foot bones (#9, 38%). The remainder of the complete bones was distributed between cranial and mandibular elements (#0, 1%), vertebral (#1, 1%), rib and sternum (#2, 1%), and lower extremity (a patella, #8, 1%).

The average length of the fragments at Fox Hollow (all bone categories pooled) is 19.4 mm (Table 4). The minimum fragment length is 2.3 mm and the maximum fragment length is 251.0 mm.

Of the 792 fragments, 73% (n = 580) of the outer surfaces was scored as heavily burned (blue-grey or white) (Figure 4) and 60% (n = 478) of the fragments was scored as heavily burned for the inner surface (Figure 5). A total of 27% (n = 210) was scored as lightly burned (brown or

TABLE 2. Counts of fragments by bone category for each of the six samples. The 12 bone groups are those listed in Chapter 3, Table 1.

Sample	0	1	2	3	4	5	6	7	8	9	10	11	n
Fox Hollow	70	37	30	4	15	29	17	4	21	14	431	120	792
Lawrence	88	56	29	0	0	5	4	5	5	2	50	10	254
Potter	57	19	9	1	1	6	14	15	17	10	53	18	220
Jerger	12	3	1	0	0	0	0	0	0	0	81	3	100
Commercial Dog	1	11	11	0	0	1	1	0	0	2	58	15	100
Commercial Human	5	3	0	0	0	0	0	0	0	0	76	16	100

TABLE 3. Percentage of fragments by bone category for each of the six samples. The 12 bone groups are those listed in Chapter 3, Table 1. Percentages are rounded to the closest whole number and therefore may not sum to 100.

Sample	0	1	2	3	4	5	6	7	8	9	10	11
Fox Hollow	9	5	4	1	2	4	2	1	3	2	54	15
Lawrence	35	22	11	0	0	2	2	2	2	1	21	4
Potter	26	9	4	1	1	3	6	7	8	5	24	9
Jerger	12	3	1	0	0	0	0	0	0	0	81	3
Commercial Dog	1	11	11	0	0	1	1	0	0	2	58	15
Commercial Human	5	3	0	0	0	0	0	0	0	0	76	16

TABLE 4. Descriptive statistics for fragment size for each of the six samples (bone categories pooled)**.**

Sample	Mean	Maximum	Minimum	n	s
Fox Hollow	19.4 mm	251.0 mm	2.3 mm	792	15.6
Lawrence	22.5 mm	67.0 mm	4.0 mm	254	9.9
Potter	33.4 mm	116.0 mm	6.0 mm	220	19.5
Jerger	14.4 mm	21.5 mm	9.2 mm	100	2.4
Commercial Dog	20.8 mm	57.7 mm	6.6 mm	100	8.6
Commercial Human	12.7 mm	39.6 mm	5.8 mm	100	5.8

black) for the outer surface (Figure 4) and 38% (n = 300) was similarly scored for the inner surface (Figure 5). No fragments were scored as unburned for the outer surface, however, 1% (n = 7) were scored as unburned for the inner surface.

A total of 34% of the fragments (n = 270) from Fox Hollow had surface fractures present. Deep transverse fracturing was the most common form, at 27% (n = 217) (Figure 6). Patina was the next most common fracture, at 4% (n = 28). A total of 2% (n = 12) showed delamination, all being cranial fragments. Both curvilinear (1%, n = 6) and longitudinal (1%, n = 7) were also noted in this sample. Similarly, only a small proportion (2%, n = 13) of the entire sample displayed warping (Figure 7).

Lawrence. In general, many more of the fragments from this sample were assigned to identifiable bone groups (Table 2). Only 25% of the sample was categorized as unidentifiable cortical or trabecular bone (categories 10 and 11) (Table 3). Cranial/mandibular fragments (#0) are the most common in this sample, at 34%. Vertebrae and ribs/sternal fragments (#'s 1 and 2) are the next most common elements in the sample, at 22% and 11%, respectively. There is a noted paucity of appendicular fragments (#'s 3, 4, 5, 6, 7, 8, and 9) present in this sample. The average length of fragments from the Lawrence sample is 22.5 mm (all categories pooled) (Table 4). The minimum fragment length is 4.0 mm and the maximum fragment length is 67.0 mm.

Of the 254 fragments, 83% (n = 210) of the outer surfaces was scored as heavily burned (blue-gray or white) (Figure 4) and 82% (n = 207) of the fragments was scored as heavily burned (brown or black) for the inner surface (Figure 5). A total of 17% (n = 44) was scored as lightly burned for the outer surface (Figure 4) and 19% (n = 47) was similarly scored for the inner surface (Figure 5). No fragments were scored as unburned for the outer or inner surfaces.

A total of 87% of the fragments from Lawrence County had surface fractures. Deep transverse and patina fractures were the most common types, at 37% (n = 95) and 34% (n = 81) (Figure 6). This sample also has a greater amount of curvilinear fracturing (6%, n = 16). In addition, 8% (n = 20) of this sample shows signs of delamination, all being cranial fragments. Warpage was also present in this sample, at 19% (n = 47).

Potter: Of the 220 fragments from the Potter sample, 68% (n = 149) was assigned to an identifiable bone category (Table 2). Cranial/mandibular fragments (category 0) are the most commonly identified in this sample. There is a discrepancy between the upper and lower extremities: upper extremity fragments (#'s 3, 4, and 5) at 4% are substantially less common than lower extremity fragments (#'s 6, 7, 8, and 9) at 25%.

The average length of fragments from the Potter sample is 33.4 mm (Table 4) (all categories pooled). The minimum fragment length is 6.0 mm and the maximum fragment length is 116.0 mm.

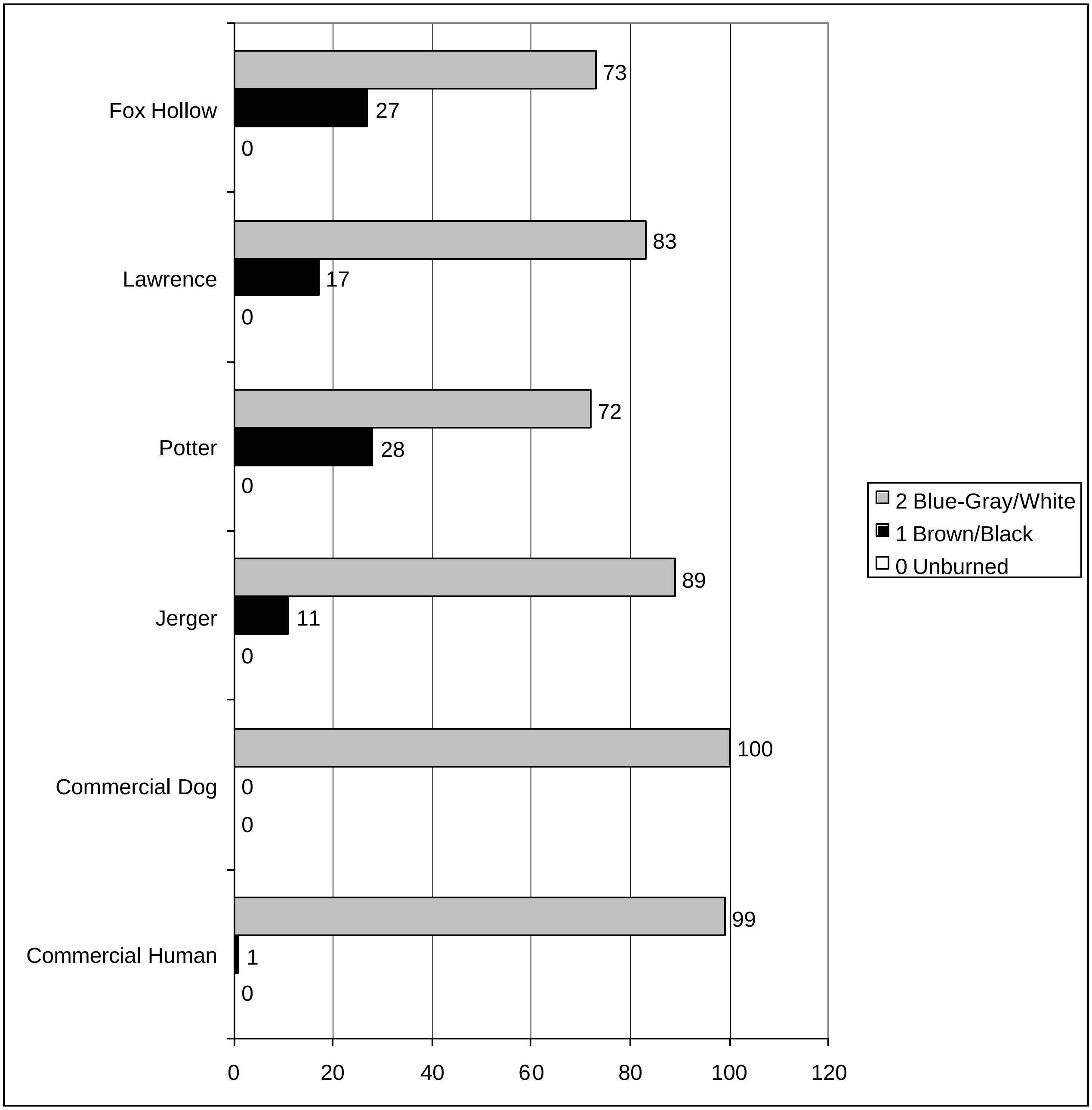

FIGURE 4. Percentages for outer surface color scores for each of the six samples.

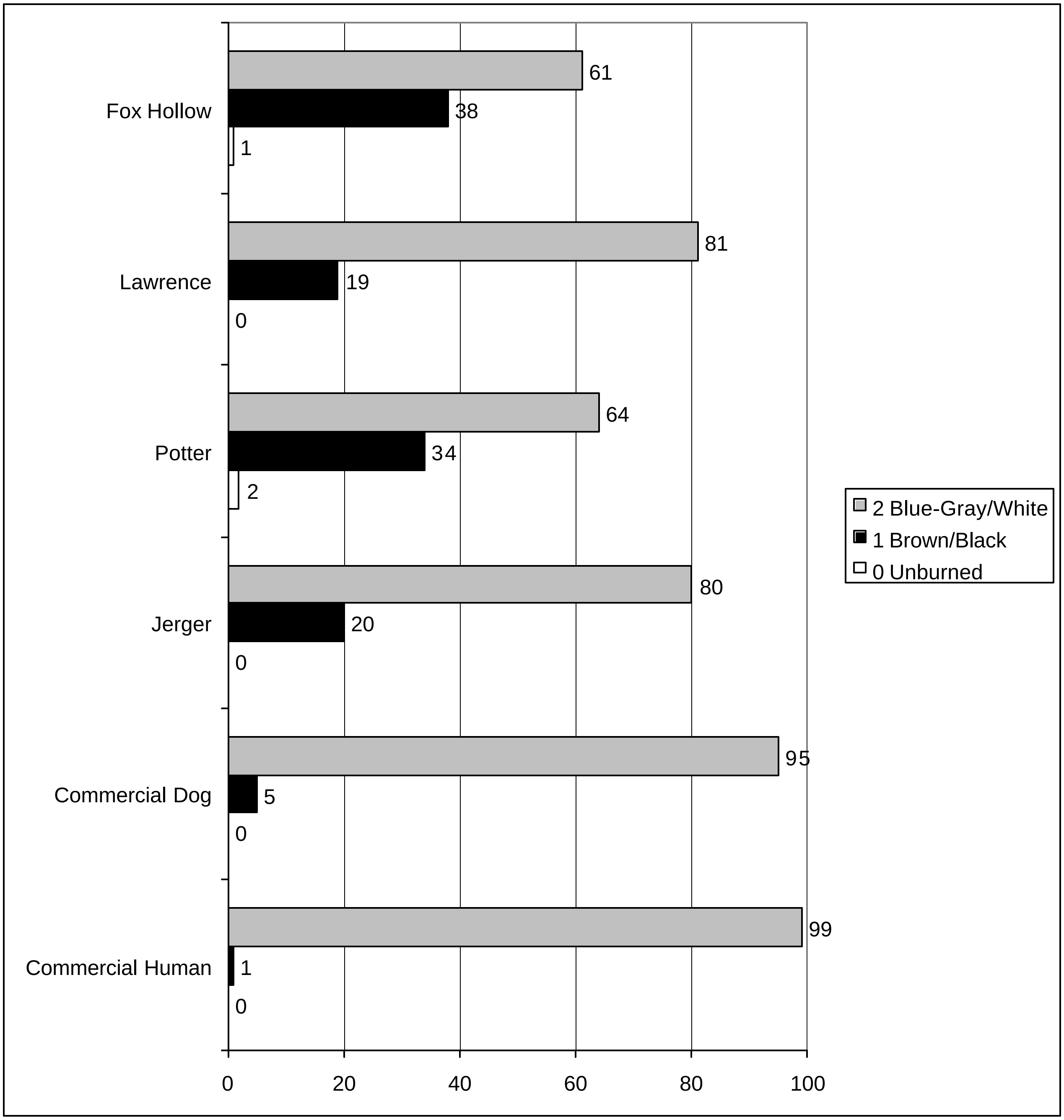

FIGURE 5. Percentages for inner surface color scores for each of the six samples.

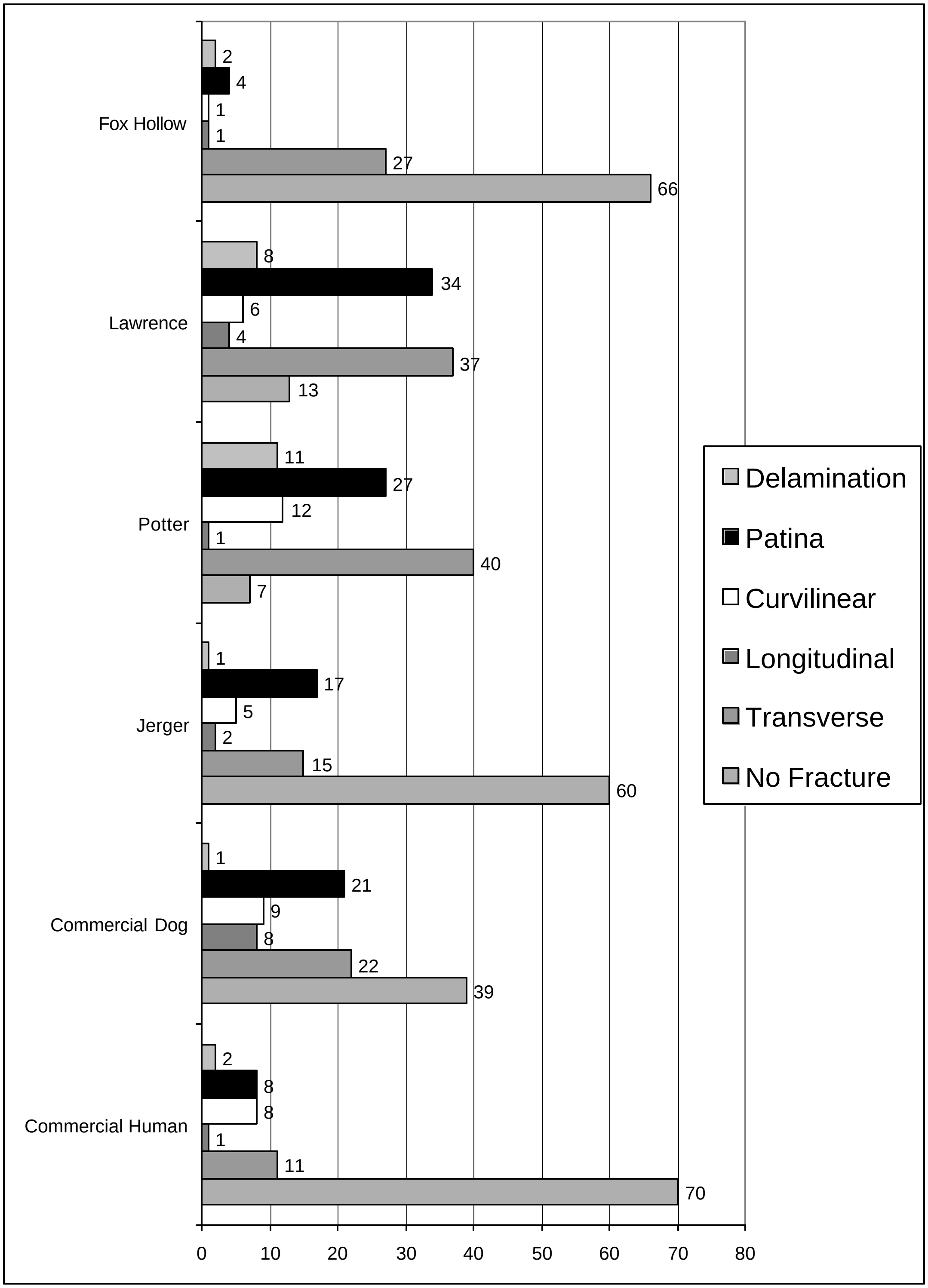

FIGURE 6. Percentages of fragments with each fracture pattern for each of the six samples.

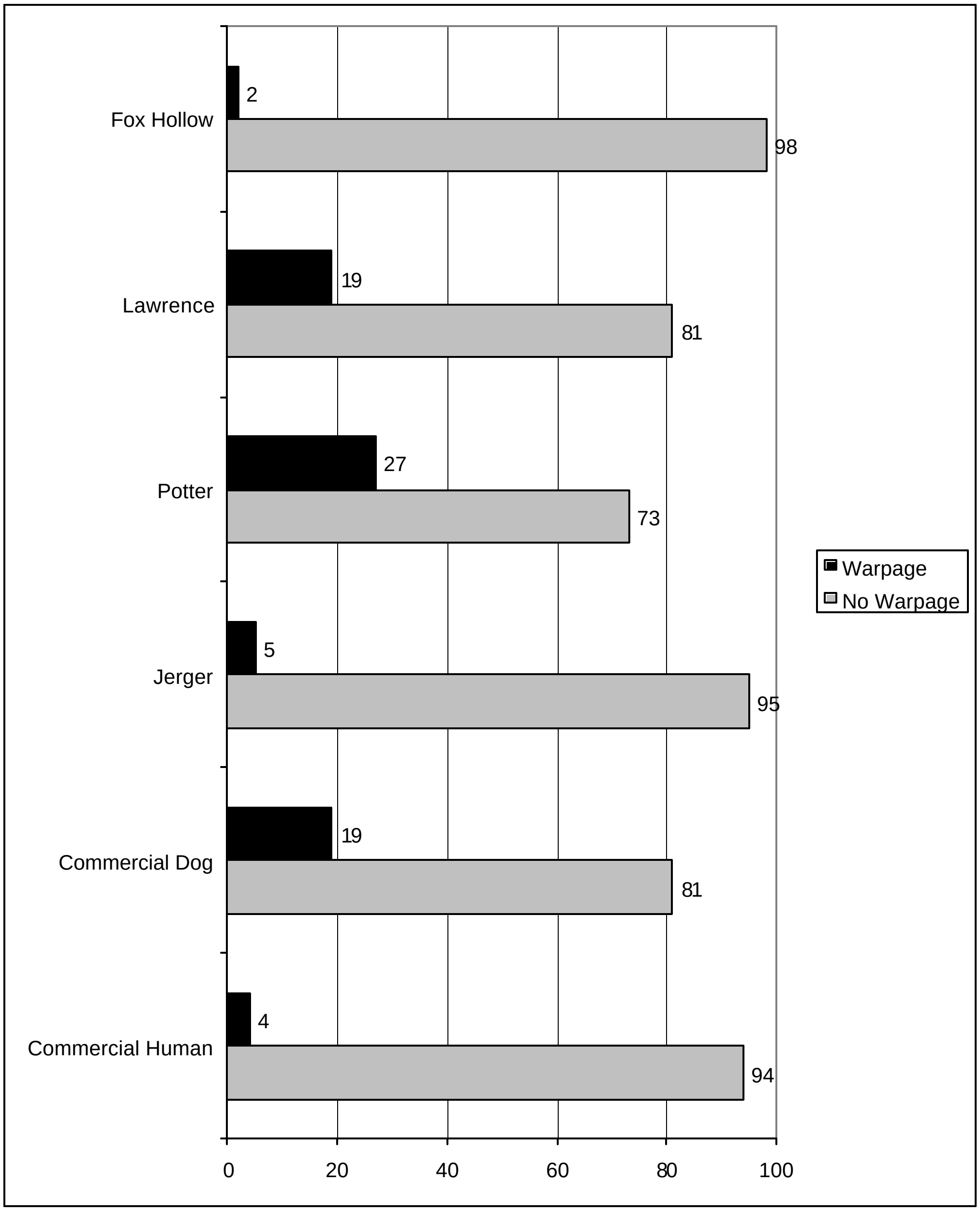

FIGURE 7. Percentages of fragments displaying warpage for each of the six samples.

Of the 220 fragments, 72% (n = 159) of the outer surfaces was scored as heavily burned (blue-gray or white) (Figure 4) and 55% (n = 121) of the fragments was scored as heavily burned for the inner surface (Figure 5). A total of 27% (n = 61) was scored as lightly burned (brown or black) for the outer surface (Figure 4) and 29% (n = 64) was similarly scored for the inner surface (Figure 5). No fragments were scored as unburned for the outer surface and a small number (n = 4) were scored as unburned for the inner surface.

A total of 93% (n = 204) of the Potter sample had surface fractures present. Deep transverse and patina fractures were the most common forms at 40% (n = 87) and 29% (n = 63) (Figure 6). However, there are also a number of curvilinear fractures present (12%, n = 26). A total of 11% (n = 25) showed delamination, all cranial fragments. Warpage was also present in this sample, at 27% (n = 59) (Figure 7).

Jerger. The Jerger sample does not have any appendicular skeletal elements identified. The majority (n = 81, 81%) of the fragments from this sample were classified as unidentifiable cortical bone (category 10) (Table 3). The next most common skeletal element identified is the cranium/mandible (#1) at 12% (n = 12).

The average length of fragments for this sample is 14.2 mm (Table 4). The minimum fragment length is 9.2 mm and the maximum fragment length is 21.5 mm.

Of the 100 fragments, 89% (n = 89) of the outer surfaces was scored as heavily burned (blue-gray or white) (Figure 4) and 80% (n = 80) of the fragments was scored as heavily burned for the inner surface (Figure 5). A total of 11% (n = 11) of the fragments was scored as lightly burned (brown or black) for the outer surface (Table 4) and 20% (n = 20) was similarly scored for the inner surface (Figure 5). No fragments were scored as unburned for the outer or inner surfaces.

A total of 40% (n = 40) of the fragments had surface fractures present. Deep transverse (n =

15, 15%) and patina fractures (n = 17, 17%) are the most common fractures (Figure 6). Curvilinear (n = 5, 5%) and longitudinal fractures (n = 2, 2%) are also present. Only 1 cranial fragment (1%) scored positive for delamination. A total of 5 fragments (5%) scored positive for warpage (Figure 7).

Commercial dog cremation. Few fragments from the commercial dog cremation could be classified into a specific bone category (Table 2). Vertebral and thoracic elements (categories 1 and 2) were the two most common bone types present (Table 3). The majority of this sample was scored as unidentifiable cortical (#10), at 58%, and unidentified trabecular bone (#11), at 15%.

The average length of fragments for this sample is 20.8 mm (Table 4). The minimum fragment length is 6.6 mm and the maximum fragment length is 57.5 mm.

Of the 100 fragments, 100% (n = 100) of the outer surfaces was scored as heavily burned (blue-gray or white) (Figure 4) and 94% (n = 94) of the fragments was scored as heavily burned for the inner surface (Figure 5). None of the fragments were scored as lightly burned (brown or black) for the outer surface (Figure 4) and 5% (n = 5) was scored as lightly burned for the inner surface (Figure 5). No fragments were scored as unburned for the outer or inner bone surfaces.

A total of 61% (n = 61) of the fragments from this sample had surface fracturing present (Figure 6). The most common fracture patterns present were transverse (n = 22, 22%) and patina (n = 21, 21%). Though present in smaller frequencies, longitudinal (n = 8, 8%), curvilinear (n = 9, 9%), and delamination (n = 1, 1%) fractures were noted. A total of 19 fragments (19%) scored positive for warpage.

Commercial human cremation. Few of the fragments from this sample were assigned to a specific bone category. The majority were scored as unidentified cortical bone (category 10, 76%) and unidentified trabecular bone (#11, 16%) (Table 3). The only other bone categories observable for this sample were cranial/mandibular (#0), at 5%, and vertebral (#1), at 3%.

The average length of fragments for this sample is 12.7 mm (Table 4). The minimum fragment length is 5.8 mm and the maximum fragment length is 39.6 mm.

Of the 100 fragments, 99% (n = 99) of the outer surfaces was scored as heavily burned (blue-gray or white) (Figure 4) and 99% (n = 99) of the fragments was scored as heavily burned for the inner surface (Figure 5). A total of 1% (n = 1) of the fragments was scored as lightly burned (brown or black) for the outer surface (Figure 5) and 1% (n = 1) was similarly scored for the inner surface (Figure 5). No fragments were scored as unburned for the outer or inner bone surfaces.

The majority of the 100 fragments (70%) did not have a fracture pattern predominating the surface of the fragment; however, a small number of fragments (n = 11, 11%) showed deep transverse fractures, curvilinear fractures (8%, n = 8), and patina (8%, n = 8) (Figure 6). Only two cranial fragments (2%) scored positive for delamination. A total of 4% (n = 4) showed warpage (Figure 7).

Comparisons Between the Samples

Bone categories. In general, there are similarities between the 6 samples with respect to bone categories present. For the majority (4/6) of the samples, the greatest number of fragments were assigned to bone category 10 (unidentifiable cortical bone) (Table 3). Jerger had the greatest percentage (81%) of its sample assigned to this bone group. In addition, Fox Hollow and the two commercial cremations each have at least 50% of their fragments in category 10. Conversely, for both the Lawrence and Potter samples, bone category 0 (cranium/mandible) is the most common fragment type at 35% and 26%, respectively, although category 10 is still notable at 21% and 24%.

All of the samples show an overall paucity of identifiable appendicular elements (categories

3, 4, 5, 6, 7, 8, and 9). In both the commercial human and Jerger samples, no appendicular elements were identified. Only 4% of the commercial dog cremation fragments were assigned to appendicular bone categories (Table 3). In the Lawrence, Fox Hollow, and Potter samples, 9%, 15%, and 31% of the fragments were appendicular elements, respectively. In the Lawrence and Potter samples, the lower extremity is slightly better represented than the upper, but the situation is reversed at Fox Hollow. Vertebra and thorax fragments (categories 1 and 2) are fairly well represented in the Lawrence (33% combined) and commercial dog (22% combined) samples, but are less frequent in the other samples (3% to 13%).

The relative prevalence of specific bone categories will be dependent on a number of factors, not all of which are taphonomic in nature. For example, certain areas of the skeleton (such as the pelvis, cranium, and vertebral column) possess a substantial surface area and/or volume and therefore would naturally be expected to produce more fragments than, say, the hands (holding fragment size constant). Other areas of the skeleton (such as the larger limb bones) contain a significant amount of dense, strong cortical bone, which would therefore predispose them to better survival and disproportional representation, compared to, say, the largely spongy sacrum.

One would expect there to be a non-random association between certain categories. For example, as the limbs become more fragmented and less identifiable, the number of unidentified cortical bone fragments should increase. For the most part, this inverse relationship is exactly what is observed here. Combining all the fragments from dense tubular long bone (categories 3, 5, 6, 8, and 9) and comparing the sums with category 10, we see that only the Lawrence sample does not fit the trend perfectly (Table 5).

TABLE 5. The relationship between long bone and cortical bone percentages.

Sample	% Long Bone Fragments	% Unidentifiable Cortical Bone Fragments	Mean Fragment Length
Jerger	0	81	14.4
Commercial Human	0	76	12.7
Commercial Dog	4	58	20.8
Fox Hollow	12	54	19.4
Potter	23	24	33.4
Lawrence	7	21	22.5

Fragment length. Of the 6 samples, the commercial human cremation has the smallest mean fragment size, at 12.7 mm, followed by Jerger (14.4 mm), Fox Hollow (19.4 mm), and the commercial dog cremation (20.8 mm) (Table 4). The Lawrence and Potter samples have the largest mean fragment sizes, at 22.5 mm and 33.4 mm, respectively.

A number of t-tests were utilized to compare the Fox Hollow fragment lengths to the other samples. Each comparison was constructed under the assumption that there was no statistical difference between Fox Hollow and the opposing sample (Table 6). Four out of the 5 comparisons made with Fox Hollow show statistically significant differences. Lawrence, Potter, the commercial human cremation, and Jerger have fragment lengths that are significantly different from the Fox Hollow sample. The only comparison in which the null hypothesis could not be rejected is between Fox Hollow and the commercial dog cremation, which are the closest in average fragment size.

TABLE 6. Student's t-test results for comparisons of fragment size.

Comparison	t-value	df	p-value
Fox Hollow vs. Lawrence County	4.58	1044	<0.05
Fox Hollow vs. Potter County	19.14	1010	<0.05
Fox Hollow vs. Commercial Dog	1.64	890	ns
Fox Hollow vs. Commercial Human	5.44	890	<0.05
Fox Hollow vs. Jerger	4.18	890	<0.05

Potter is the most different from Fox Hollow. This difference may be attributed to the fact that the Potter specimen was ruled an accidental burning and the individual was found in rough anatomical position. The remains were not significantly disturbed after the burning event. The remains from Fox Hollow were burned and then subjected to fluvial transport (see Chapter 5).

Fragment size in the other samples was also affected by postmortem processes. The commercial human cremation was subjected to high temperatures for long periods of time. This process leaves the bone extremely fragile because the bone is reduced to a calcined state. From the documentation that accompanies this particular specimen, it is known that the bone was then pulverized in a grinding machine. The Jerger sample is a product of Early Archaic funerary rituals. The bones were first rendered fragile by the burning process, and hundreds of years of compression in the earth followed by farm tilling have broken these fragments into even smaller pieces. Mean fragment size for the commercial dog cremation is also small, but unlike the commercial human cremation, it was not pulverized after the crematory process. However, these fragile remains have been used as teaching specimens for a number of years and have been subjected to storage and handling. In addition, they had been mailed to Indiana from New York. Over time the highly burned bone has broken and crumbled.

Table 5 also includes a column showing mean fragment size for each of the samples. While the association is not perfect, there is clearly a trend for the percentage of unidentifiable cortical bone fragments to increase as the mean fragment size decreases. The smaller the fragment, the more difficult it is to identify.

Coloration. All 6 samples are significantly damaged by fire; however, there are differences in the degree to which this damage is expressed (Figures 4 and 5). Both the commercial human and dog cremations show the greatest degree of fire alteration, with nearly all fragments being heavily burned (blue-gray to white) on both surfaces. The Jerger and Lawrence samples also have a large proportion of fragments scored as heavily burned, reaching or exceeding 80% for both surfaces.

The Potter and Fox Hollow samples show the lowest degree of burn damage, with percentages of heavily burned fragments just exceeding 70% for the outer surface and just exceeding 60% for the inner surface. There is an inverse relationship between the burn categories. For example, Fox Hollow and Potter display the largest proportions of lightly burned (brown to black) fragments, in both cases approaching 30% on the outer surfaces and approaching 40% on the inner surfaces, and they show only moderate levels of heavy burning. Lawrence and Jerger are intermediate with respect to the proportion of lightly burned to heavily burned fragments, while the commercial cremations show the lowest proportions of light burning. This inverse relationship is predictable in that as the sample is exposed to increasing levels of heat, more and more fragments are converted from the lightly burned category to the heavily burned category. Theoretically, these fragments will also be getting smaller in the process.

It should be noted that burning is generally lighter on the inner surfaces compared to the outer. This may be simply a function of exposure. As flesh and soft tissue is removed from the bone surface by fire, the underling outer bone is exposed. Until the bone fractures, however, the inner surface of the bone is partially protected from the heat. The outer bone surface is subjected to more heat for a greater duration of time and therefore it incurs more heat damage than the inner surface up to the point where the entire fragment becomes completely calcined.

In retrospect, combining the blue/gray and white color categories after Green and Schmidt (2000) may have reduced the sensitivity of the indicator, resulting in less precise comparisons between samples. Additional differences may have been detected using a 4-point scale. For example, there is a hint that coloration is associated with mean fragment size. The least burned sample (Potter) has the largest fragment size, while the sample with the smallest fragment size (commercial human) has nearly the greatest degree of burning, as measured by the percent of fragments that are heavily burned. However, as the percentages approach 100, distinctions between groups will become less prominent. With only two categories of color for burned fragments, it is

TABLE 7. Percentages of fragments with each fracture type as related to fragment size, by sample.

Sample	Mean Length	Delam.	Patina	Curv.	Long.	Trans.	None	Warpage
Potter	33.4	11	27	12	1	40	7	27
Lawrence	22.5	8	34	6	4	37	13	19
Commercial Dog	20.8	1	21	9	8	22	39	19
Fox Hollow	19.4	2	4	1	1	27	66	2
Jerger	14.4	1	17	5	2	15	60	5
Commercial Human	12.7	2	8	8	1	11	70	4

difficult to pin down the relationship between degree of burning and fragment size.

Fracturing and warpage. In all 6 of the samples there are examples of each of the 5 fracture patterns scored (transverse, longitudinal, curvilinear, patina, and delamination) (Figure 6). However, like color patterns, each fracture pattern varies in frequency between the samples. For Fox Hollow, the commercial human cremation, and Jerger, the majority of the fragments (60 to 70%) did not display surface fracturing. The Lawrence, Potter, and commercial dog cremation samples, on the other hand, have a greater proportion of scorable fracture patterns, with 61% to 93% scored as present.

It is clear that the scorability of surface fracturing is related to overall fragment size. The samples with the lowest mean fragment length (commercial human cremation, Jerger, and Fox Hollow) have the largest percentages of fragments with no surface fracturing. Table 7 shows that this inverse is nearly perfect across samples. It is likely that surface fractures become enlarged as they become eroded, transported, or commercially pounded, breaking into smaller pieces and thus removing the signs of fracture lines from the surfaces of the fragments.

Delamination is found in small proportions in all of the 6 of the samples. Potter and Lawrence have the greatest proportions of delamination (11 and 8%, respectively). However, both samples have a greater proportion of fragments identified as cranial, and both have large fragment sizes. This high delamination values may simply be a product of availability and size.

The Potter, Lawrence, and commercial dog samples have large proportions of fragments (21 to 34%) displaying patina fracturing. It is no coincidence that these samples also have the largest mean fragment size (Table 7). It seems that patina fracturing is easily masked by post-burning events and is more likely to be found on bones that have been burned but not subjected to excessive fragmentation.

On the other hand, there is no simple relationship between curvilinear fractures and fragment size or between longitudinal fractures and fragment size. However, the percentages are very low for both types of fractures in most samples, so any conclusions would be tentative. Transverse fracturing displays a strong direct relationship with fragment size (Table 7). The samples with the largest fragments (Potter and Lawrence) have the greatest percentages of transverse fractures. The commercial human sample, with the smallest fragments, displays the lowest percentage of transverse fractures.

The majority of the fragments from the 6 samples did not show signs of warpage, with the highest values being Potter (27%), Lawrence (19%), and the commercial dog cremation (19%). Fox Hollow, the commercial human cremation, and Jerger displayed nominal amounts of warpage, ranging from 2% to 5% (Figure 7). As shown in Table 7, there is a fairly direct relationship between the presence of warpage and fragment size.

It is clear that the presence of many if not most fractures and deformation is strongly associated with fragment size. Unfortunately, most cremation studies that have examined fracture patterns have not rigorously controlled for fragment size. To the extent that fracture patterns may be able to reveal information about the condition of the bone at the time of burning, skeletal biologists must be cautious not to over interpret remains that have been heavily modified by post-burning processes or that have been extensively burned for long durations.

How Does Fox Hollow Farm Measure Up?

The purpose of examining the additional 5 samples is to make comparisons with the Fox Hollow assemblage. Similarities or differences between Fox Hollow and the other samples may help us to ascertain what happened at Fox Hollow, assuming that we know sufficiently what happened to the other samples.

Table 8 lists the samples that most closely resemble Fox Hollow in each of the main categories of observations. Some of the comparisons are not particularly informative because of low frequencies of certain traits in some categories or samples. For example, while Fox Hollow and the commercial human cremation both have the same percentage of delaminated fragments (2%), the commercial dog and Jerger Samples are very close (1% each). A similar problem exists for longitudinal fractures. Most of the remaining comparisons, however, have more validity. Fox Hollow is most similar to the commercial dog cremation 5 times (primarily in bone category percentages and fragment size) and to the commercial human cremation 4 times (in fracture types). Potter comes in with 3 appearances, Jerger appears twice, and Lawrence not at all.

While not definitive, this pattern is suggestive. Fox Hollow is most similar to the commercial dog and commercial human cremations and least similar to the recent forensic cases (Potter and Lawrence) or the archeological assemblage (Jerger). While these results may not seem intuitively obvious, they may be explained by certain occurrences at the Fox Hollow Site.

For example, there is evidence of sequential or cumulative burnings at Fox Hollow Farm (Nawrocki et al. n.d.). It seems that Baumeister did not burn the victims in Area 1 all in one burning event. This suggestion is supported by the archeological evidence (for example, unburned bone found on top of burned debris). If the assailant was not burning all the victims at once, then the first victim burned may have been a part of all the subsequent burning events that followed. Therefore, with each additional burning, the remains of the earlier victims were subjected to high temperatures over and over again, causing extensive heat damage and fragmentation not unlike the heat damage experienced in modern cremations.

TABLE 8. Comparisons of Fox Hollow to the other five samples.
Parentheses indicate ties or unclear results.

Fox Hollow Most Closely Resembles …	In…
Jerger	% of cranial fragments
Potter	% of vertebra and thoracic fragments
Commercial Dog	% of long bone fragments
Commercial Dog	% of unidentified cortical bone
Commercial Dog	% of unidentified trabecular bone
Commercial Dog	fragment size
Potter	color of outer surface
Potter	color of inner surface
(Commercial Human)	delamination
Commercial Human	patina
Jerger	curvilinear fractures
(Potter & Commercial Human)	longitudinal fracture
Commercial Dog	transverse fractures
Commercial Human	% with no fractures
Commercial Human	warpage

In addition, unlike the other forensic cases, the Fox Hollow assemblage was not contained in a small, relatively undisturbed area. The Fox Hollow cremains were distributed over approximately 80 square meters by water from the gutter system of the main dwelling. This distribution occurred over several years and would have caused the already fragile bone to fracture further and become smaller and smaller with accumulated exposure. The cumulative effects of sequential burning, water action, and time would have produced an assemblage that looks more similar to the handled and pulverized commercial cremations.

CHAPTER 5: FLUVIAL TRANSPORT AT FOX HOLLOW

Distribution Patterns at Fox Hollow

The distribution of the large Fox Hollow dataset (n = 5651) gives us our first glimpse at an identifiable pattern in Area 1 (Figure 8). Grids 1A and B, where the burning events most likely occurred (Nawrocki et al. n.d.), held the largest proportion (69%) of fragments recovered. Most of the remaining fragments were recovered from the grids located in or immediately adjacent to the drainage channel. It should be noted that one downstream grid placed to the southwest of the channel (Grid 11) disproportionately held a large number (373) of fragments. There is a tree blocking the channel at the base of this particular grid, creating a dam that slowed the water and allowed the fragments held in the water to precipitate out of the flow (Nawrocki et al. n.d.). Beyond this point, very few fragments were found.

Bone categories. In order to identify more specific patterns, the second Fox Hollow dataset (n = 792) was examined and the fragments were subdivided by grid to determine if there is a non-random distribution to bone categories in Area 1. As seen in Table 9, for the 8 grids that contained at least 100 fragments, upper extremity/hand bone fragments (categories 3, 4, 5, and 6) and lower extremity/foot bone fragments (categories 8 and 9) are more prevalent at the top of the grid (uphill) than at the bottom of the grid (downhill), while cranial and axial skeletal elements such as the ribs, sternum, and vertebrae (categories 0, 1, and 2) are seen in fairly equal proportions at both ends of the grid system. A chi-squared test shows that the overall distribution of fragments by category within the grid system is non-random when excluding the unidentified fragments (categories 10 and 11) ($\chi 2 = 95.171$, $p < 0.005$, df = 63).

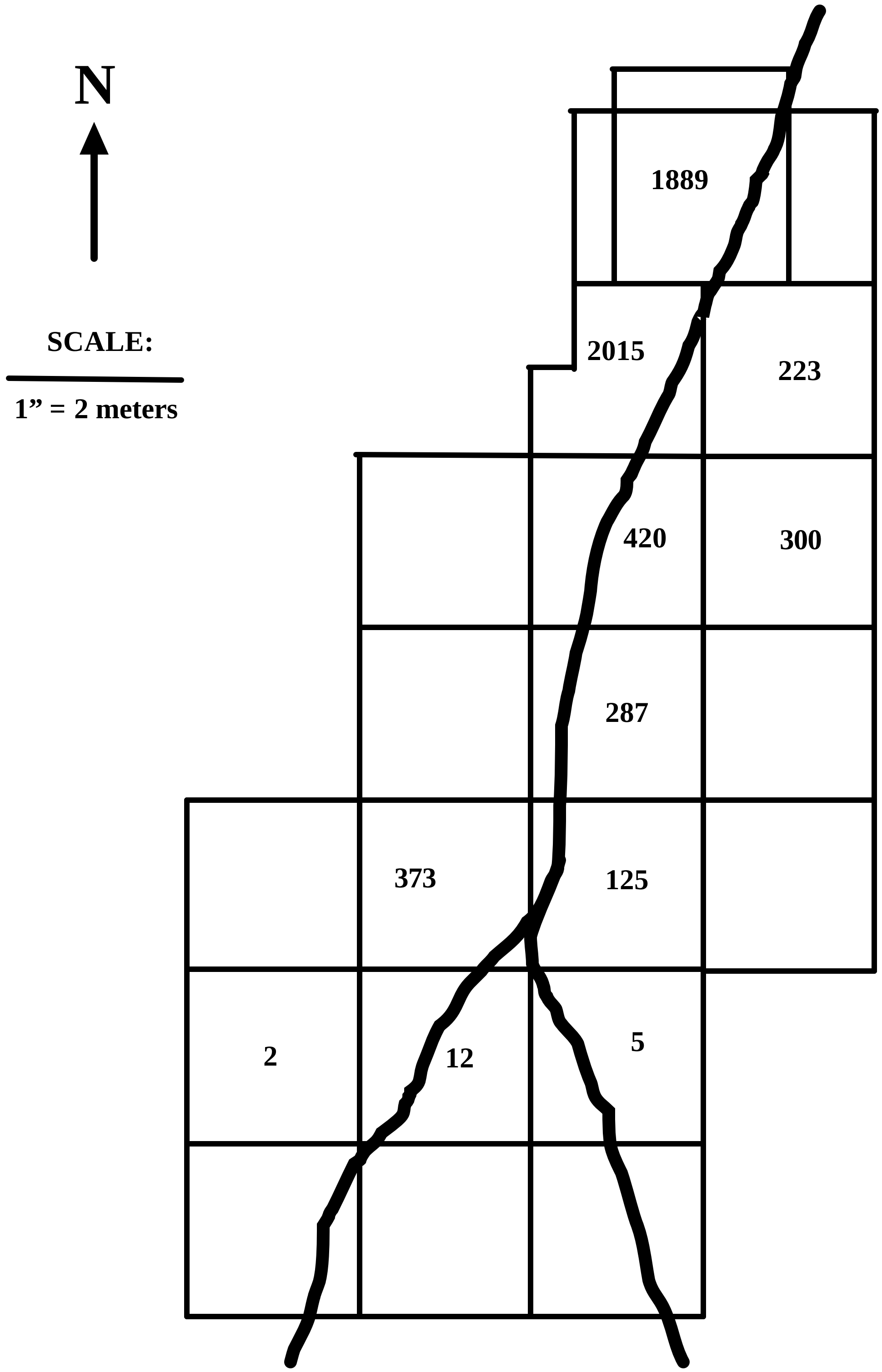

FIGURE 8. Counts of all fragments per grid in Area 1 (including the drainage channel).
Refer to Figure 2 for grid numbers (after Nawrocki et al. n.d.).

TABLE 9. Counts of bone categories (columns) per grid (rows). Bone categories are listed in Tables 1 and 11. In general, grid numbers increase as one moves downhill.

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1A	9	7	7	0	2	12	7	0	7	6	30	12
1B	14	7	6	3	2	7	5	2	5	3	31	13
2	5	1	2	0	5	2	1	0	1	0	55	28
3	3	6	3	1	1	2	3	0	1	2	62	15
4	8	2	3	0	2	0	0	0	1	1	79	3
7	9	4	0	0	1	2	0	0	3	0	76	5
10	15	2	3	0	1	1	0	0	0	0	56	22
11	7	8	6	0	1	3	1	2	3	2	42	22
total	**70**	**37**	**30**	**4**	**15**	**29**	**17**	**4**	**21**	**14**	**431**	**120**

TABLE 10. Counts and percentages of bone fragments (columns) per grid (rows). Axial groups and appendicular groups are combined.

	# axial	**%**	**# append.**	**%**
1A	23	**16**	34	**34**
1B	29	**21**	25	**25**
2	8	**6**	9	**9**
3	12	**9**	10	**10**
4	13	**9**	4	**4**
7	13	**9**	6	**6**
10	20	**14**	2	**2**
11	23	**16**	10	**10**
total	**141**	100%	**100**	100%

The data in Table 9 can be condensed further by combining cranial and axial fragments (categories 0, 1, 2, and 7) into a single group ("axial") and appendicular fragments (categories 3, 4, 5, 6, 8, and 9) into a separate group ("append."). The few pelvis and sacrum fragments (category 7, n = 4) were included as axial elements because of their primarily spongy construction (see later). As can be seen from Table 10, a larger proportion of the axial elements were found in the lower grids, and a larger proportion of the appendicular elements were found in the upper grids. Even so, it is clear that all types of bone fragments can move downhill under the right conditions.

Fragment size. When looking at the average length of bone fragments by category, it appears that some body parts tend to be bigger than others (Table 11). For example, the mean size for all identifiable clavicular fragments (category 3) is 50.6 mm (n = 4). These fragments are not found in the grid system beyond (downstream of) Grid 3 (Table 9). On the other hand, the mean size for cranial fragments (category 0) is 18.4 mm, and those fragments have traveled the length of the grid system. Therefore, their differential transport may be a function more of their size than of their shape or morphology. The relationship between fragment size and transportability probably explains the majority of the non-random distribution of the bone categories across the grid system. Cranial fragments are smaller and transport more easily, while the larger limb elements tend to lag behind. Unidentified fragments, because they are the tiniest of all, are also well-distributed across the grid.

Table 12 presents mean fragment length by grid. It is clear that the upper grids contained larger fragments than the lower grids. An ANOVA using fragment length as the dependent variable and grid number as the categorical independent variable was employed to determine if this difference is significant, and Table 13 presents the obvious outcome.

TABLE 11. Mean fragment length by bone category, arranged in descending order of size.

Bone Categories	Mean Fragment Length (mm)	n	s
3 - clavicle	50.6	4	2.6
7 - pelvis & sacrum	49.2	4	8.2
8 - femur, tibia, fibula, & patella	45.4	21	16.3
9 - foot	41.2	14	52.0
6 - hand	40.0	17	56.4
5 - humerus, ulna, & radius	37.4	29	16.0
2 - ribs & sternum	32.6	30	16.9
1 - vertebrae	21.7	37	7.3
4 - scapula	19.5	15	6.3
0 - cranium & mandible	18.4	70	7.1
10 - unidentified cortical	15.1	431	5.9
11 - unidentified trabecular	15.1	120	6.2

TABLE 12. Mean fragment length per grid.

Grid Number	Mean Length (mm)	% Heavily Burned	n
1A	29.9	63%	99
1B	29.4	59%	98
2	14.5	84%	100
3	16.0	78%	99
4	15.3	82%	99
7	17.0	67%	100
10	14.5	88%	100
11	19.2	65%	97

TABLE 13. ANOVA results using fragment length as the dependent variable and grid as the independent variable. The model employed was: fragment length = grid + error.

Sum of Squares	df	Mean square	F	p
28976.942	7	4139.563	19.794	<0.0001

Why are some fragments, such as those from the cranium and axial skeleton, smaller than others, such as those from the limbs? A number of factors could have contributed to differential fragmentation during and subsequent to burning. First, some elements, such as the cranial vault, face, ribs, and vertebral neural arches, are less well protected in the body. The limb bones tend to be covered by heavy muscle masses that would serve to delay the entry of heat. Second, other elements, such as the vertebral bodies, ribs, pelvis, long bone epiphyses, and the cranial base, contain considerably more spongy bone in proportion to dense cortical bone than do the long bone shafts, making the former examples more susceptible to thermal damage. Thirdly, some bones, like those of the face and scapula, are comprised of thin, fragile plates that break easily. Finally, the assailant may have expended special effort to make sure that certain highly recognizable or identifiable elements, such as the skull and face, hands, or pubic area, were thoroughly consumed by the fire.

Holding fragment size constant, the greater density of the thick cortical bone in the long bone shafts would seem to make those fragments less susceptible to fluvial transport than spongy axial elements or thin cranial fragments. A hint of this relationship can be seen in Table 9 -- while the unidentified cortical bone fragments have the same mean size as the unidentified trabecular bone fragments (15.1 mm -- Table 11), a greater proportion (44/120, or 37%) of the spongy bone fragments are found in the lowest grids (10 and 11), whereas only 23% (98/431) of all cortical bone fragments are found in these grids.

In summary, the combined transportability and fragility of cranial and axial elements would tend to create a dynamic feedback loop -- the further they move, the more fractured they will become, making them even smaller and more transportable.

Fragment color. Table 12 also presents the percentage of fragments in each grid that are heavily burned (calcined, or blue-gray/white). It can be seen that the degree of burning generally increases as one moves downhill across the grid system. A chi-squared test indicates that this distribution is non-random ($\chi 2 = 42.91$, $p < 0.000$, df = 7). It is also apparent that the grids that have the smallest fragments also contain the most highly burned fragments. In fact, the Pearson correlation between the degree of burning and fragment length across grids is $r = -0.824$ ($p = 0.012$, $n = 8$). This relationship is predictable -- more thorough burning results in smaller fragments, which are more susceptible to transport, which in turn subjects them to more fracturing.

Another way of illustrating this relationship is presented in Figure 9. The numbers in each grid were calculated as follows:

$$\frac{\textbf{Mean Length x 100}}{\textbf{\% Heavily Burned}}$$

The larger the resulting index, the larger the fragment size and the lower the degree of burning. Lower indices indicate smaller fragments and higher burning. As can be seen, the highest indices are in Grids 1A and 1B, at the top of the hill, and the smallest index is at the bottom, although the relationship is far from perfect, probably reflecting local differences in channel diameter, slope/grade, and terrain.

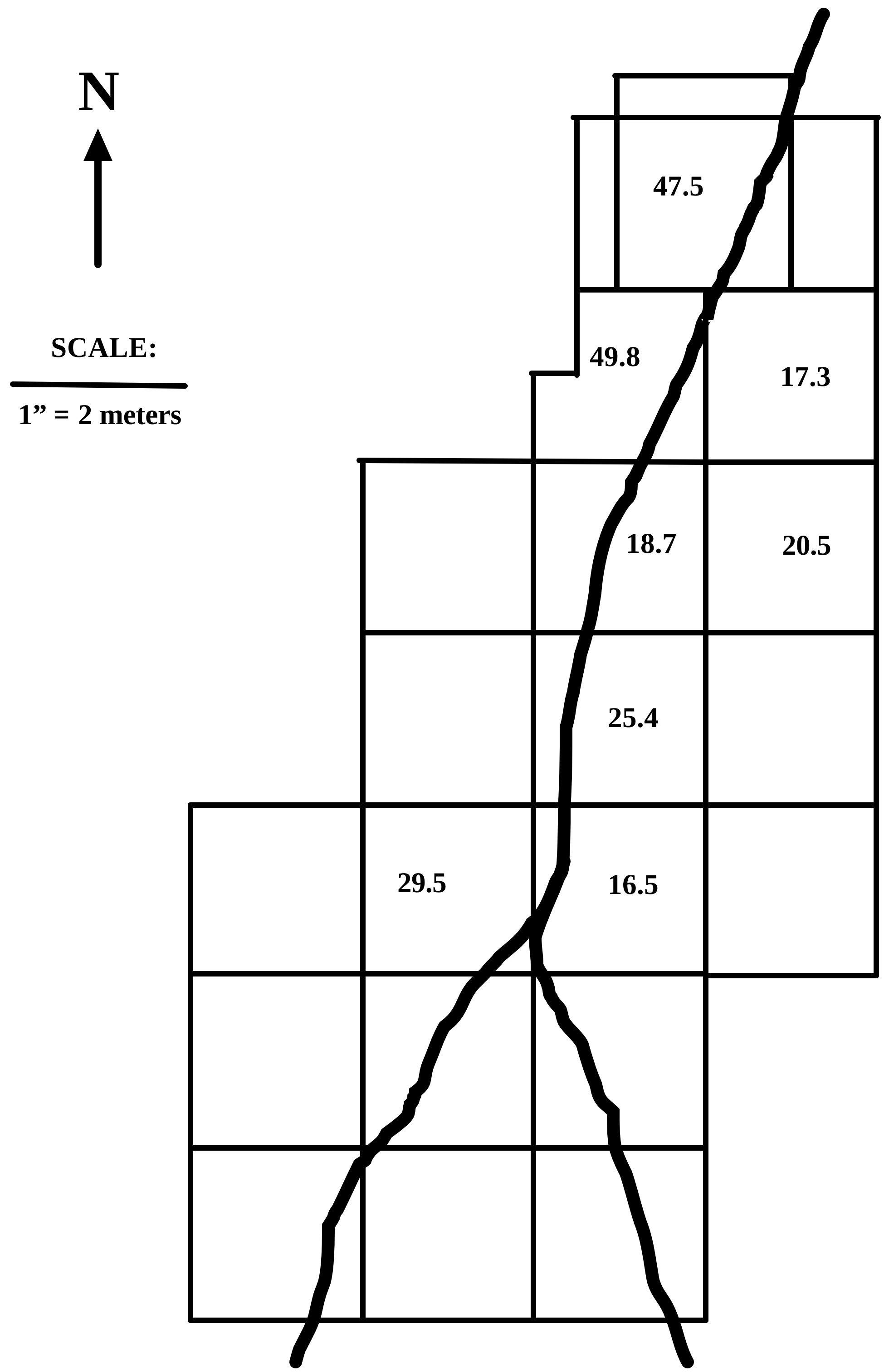

FIGURE 9. Area 1 site plan (including the drainage channel) plotting the size/burning index as described in the text.

CHAPTER 6: DISCUSSION AND CONCLUSIONS

In this study, the following research questions were posed with regard to the remains recovered from Area 1 of Fox Hollow Farm:

1. What was the condition of the remains (fresh or dry) at the time of the burning?
2. What taphonomic processes contributed to the distribution of remains over Area 1?
3. Can assailant behavior be deciphered from the scientific data?

In order to answer these questions, I scored various traits of burned remains (color, fracture pattern, warping, and delamination) and compared the Fox Hollow Farm remains to other burned assemblages of known origin. Statistical analysis was designed to (1) compare and decide if the Area 1 remains are significantly different from other forensic, prehistoric, or commercial cremains, and to (2) determine whether the remains from Area 1 are distributed randomly within the grid system.

Burning

It has been suggested that no one characteristic of burn damage can provide a clear picture as to the state of the remains prior to burning. However, by looking at all characteristics present in a sample, one may be able to begin to draw some tentative inferences. Many authors agree that characteristics of remains burned in a dry state can differ from those burned in a fleshed or wet state (Baby 1954; Binford 1963; Buikstra and Swegle 1989; Ubelaker 1999). The differences can be attributed to the presence or absence of fats and residual tissues in the bones. Remains burned in a dry state tend to become smoked in color, present shallow superficial fracturing, and display little warpage. Conversely, those remains burned in the fleshed/wet state exhibit a range in coloration from brown/black to white and display deep transverse/longitudinal fracturing, delamination, and marked warping.

The remains from Area 1 of Fox Hollow Farm display a suite of burn damage characteristics consistent with remains that have been exposed to high temperatures for a long period of time. The majority of the fragments are completely calcined on both outer and inner surfaces. Some fragments display deep transverse, longitudinal, and curvilinear fractures, and some are warped, suggesting that the remains were burned with tissues and fats still present. Delamination of the external table of the cranial vault is also present; this type of fracture is not normally noted in dry remains that are burned.

However, many of the fragments from Fox Hollow are very small and thus do not present many surface fractures for examination. To fully appreciate the degree to which a fragment has been altered from its original condition, enough of the fragment must remain to be analyzed. Extensive cremation and fragmentation of fragile burned bone will effectively remove much of the evidence used by the anthropologist to infer the original condition of the remains.

The majority of the unburned elements from Area 1 are hand and foot bones and anterior teeth. These elements are typically the first to fall away from a moderately decomposed corpse; therefore it can be inferred that the victims represented in Area 1 may have been left to decay and dry out for a period of time before the burning events (Nawrocki et al. n.d.). This assumption is supported by the archeological work at the site. Field notes and photographs document several instances where complete unburned bones and teeth were found on top of burned material. It is therefore possible that some dry bones eventually became burned as later victims were set afire. Unfortunately, it would be difficult to discern exactly how much bone was burned dry because even wet bone will produce some fragments that do not have the characteristics of wet burning.

Comparisons of the Fox Hollow assemblage to other burned remains with known histories indicates that the pattern of characteristics is more like that seen in commercial human and dog cremations and least similar to accidental burnings. This finding suggests that Baumeister's actions did indeed cause increased, sequential thermal damage to the remains, and the Fox Hollow assemblage can indeed be called a "cremation" -- e.g., *the purposeful reduction of human remains via burning and post-burn processing*. However, natural events also may have affected the condition of the remains.

Fluvial Transport

Unlike the burning, it seems that the assailant in this case had less to do with the overall distribution of the remains throughout the grid system in Area 1 than did water action. It was assumed that if the assailant distributed the remains via means such as raking or tossing, the pattern of dispersal would be more or less random. However, it is clear that the distribution pattern of fragment size and color is non-random within the grid system.

The grids downhill of the main burn area hold highly burned small fragments. In fact, a simple correlation shows that the smallest fragments are also the most highly burned, and these fragment are more likely to have been found along the gentle washout on the southeast side of the channel.

It is also clear that fragments of identifiable body parts are non-randomly distributed. However, the lag and transport groups as defined by Boaz and Behrensmeyer (1976) do not seem to apply to the distribution seen in Area 1. Cranial fragments were found in fairly equal proportions at the top and bottom of the grid system, while hand and foot bones tended to stay near the top of the grid system. Hands and feet were less burned and therefore were larger and heavier than other skeletal fragments, resulting in their resistance to movement under gentle currents. Cranial fragments, being more heavily burned and smaller, were easily swept in the slow currents and therefore distributed more evenly downslope.

Recommendations for Further Study

In retrospect, some benefit could have been obtained by using the actual weight of the skeletal material instead of just length as a measure of size. This study generalized that the small fragments are the most highly burned and therefore would have been the lightest fragments. In reality, however, it is difficult to control for actual density without more detailed measurements. Additionally, a proper flume study could be conducted to determine how burned bone fragments actually move in water.

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