To the Graduate School:

We are submitting herewith a thesis written by Joanne Lorraine Bennett entitled "Thermal Alteration of Bone: Experiments in Post-burial Modification". We have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Anthropology.

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Thermal Alteration of Bone: Experiments in Post-burial Modification

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Abstract

Burned bone is a common component of archaeological deposits. Hearth features, fire-cracked rock, charcoal and ash are commonly associated with burned bone. However, such direct evidence of fire is not always present in the archaeological record. Nevertheless, burned bone has been associated with culinary activities, waste disposal, use as fuel, and as a by-product of naturally occurring fires. Such interpretations are based upon the assumption that the agents responsible for burning act upon the bone prior to deposition or burial.

The sequential relationship between thermal alteration and deposition is continuously incorporated into the analysis of burned material. However, it has been suggested that post-burial alteration of skeletal material is not only possible, but may in fact, serve to explain the condition of burned material recovered in certain situations (see David 1990 and Lyman 1994). Furthermore, exposure to heat following deposition and or burial incorporates several additional variables. The sediment in which bone is deposited, duration of exposure to a heat source, and the interval between burial and burning are factors that affect the extent of thermal alteration. The focus of this research is to test the assumptions surrounding subsurface, (i.e., post-burial), alteration by surface fires.

Experiments, both forensic and archaeological, have been conducted to determine features which characterize post-burial burning. Macroscopic and

microscopic evaluation of these experimental materials with respect to the traits associated with bone burned through direct exposure to heat, yield intriguing and important results.

Table of Contents

Chapter		Page
I	**Introduction**	1
	Taphonomy	2
	Fire in the Archaeological Record	4
	Archaeological Evidence	6
	Project Aims	11
II	**Literature Review**	13
	Introduction	13
	Bone Structure and Chemistry	14
	Gross Structure	14
	Microstructure	15
	Bone Cells	15
	Molecular Composition	16
	Thermal Alteration and Bone Structure	17
	Burned Bone Research	19
	Crematory Investigation and Pre-incineration Condition	20
	Laboratory Experimentation	22
	Color	22
	Microscopy	24
	Replicative Experimentation	27
	Conclusions	29
III	**Materials and Methods**	30
	Introduction	30
	Material	31
	Modern Bone Sample	31
	Archaeological Bone Sample	33
	Laboratory Comparative Sample	33
	Archaeological Fire Model	36
	Forensic Fire Model	40
	Excavation and Recovery	43
	Temperature Estimation	43
	Macroscopic Evaluation	44
	Color	45
	Fractures	45
	Warping	45

Microscopic Examination 45
Stereomicroscopy 46
Conclusions 46

IV **Results** 48
Laboratory Comparative Sample 48
Color 48
Fractures 52
Stereomicroscopy 52
Archaeological Fire Model 52
Temperature 55
Color 60
Fractures 64
Warping 64
Stereomicroscopy 67
Forensic Fire Model 69
Temperature 70
Color 71
Fractures 73
Warping 73
Stereomicroscopy 73

V **Discussion** 75
Color 76
Fracture and Warping 78
Experiment 80

VI **Conclusions** 86

References Cited 89

Appendix 98

Vita 105

List of Figures

Figure		Page
1.	Skutt Electric Kiln, model 1227	35
2.	Aerial Schematic of Units in Archaeological Fire Model	37
3.	Profile Schematic of a Unit in Archaeological Fire Model	38
4.	Floor Plan of Single Story House with highlighted aerial schematic of Forensic Fire Model	42
5.	Temperatures Recorded During Archaeological Fire Model	56

List of Tables

Table **Page**

1. Five stages of heating temperatures and associated colors as determined by Shipman et al. (1984)..... 23
2. Three classes of heating temperatures and associated colors, SEM and x-ray diffraction as determined by McCutcheon (1992)..... 25
3. Five stages of heating temperatures and associated microscopic morphology as determined by Shipman et al. (1984)..... 25
4. Four stages of heating, color and associated microscopic morphology as determined by Nicholson (1993)..... 26
5. Totals of Bones used in Investigation..... 44
6. Surface colors identified on kiln heated specimens..... 49
7. Microscopic appearance of specimens heated at 70x magnification..... 53
8. Soil colors identified during excavations of Archaeological Fire Model..... 54
9. Initial subsurface temperatures recorded in Archaeological Fire Model..... 55
10. Maximum subsurface temperatures attained in Archaeological Fire..... 57
11. Hour at which maximum subsurface temperatures were attained in Archaeological Fire Model..... 58
12. Hour 1 to Hour 10 mean subsurface temperatures attained in Archaeological Fire Model..... 59
13. Hour 11 to Hour 48 mean subsurface temperatures attained in Archaeological Fire Model..... 59
14. Colors identified on specimens in Archaeological Fire Model..... 61
15. Fractures recognized on specimens in Archaeological Fire Model..... 67
16. Microscopic appearance of modern weathered segments in Archaeological Fire Model at 70x magnification..... 68
17. Microscopic appearance of Archaic specimens in Archaeological Fire Model at at 70x magnification..... 69
18. Approximate maximum temperatures attained in Forensic Fire Model..... 70
19. Colors identified on specimens in Forensic Fire Model..... 71
20. Microscopic appearance of specimens in Forensic Fire Model at 70x magnification..... 74
21. Colors identified on specimens heated in electric kiln for 48 hours..... 80

List of Plates

Plate		Page
1.	Late Stage 1, early stage 2 Sectioned Modern Metapodial	32
2.	Modern Weathered Segments Heated in Electric Kiln	50
3.	Archaic Specimens Heated in Electric Kiln	51
4.	Modern Weathered Segments from depths of 10 cm and 5 cm in Archaeological Fire Model	62
5.	Archaic Specimens from depths of 10 cm and 15 cm in Archaeological Fire Model	63
6.	Modern Weathered Segments from depths of 2 cm and 5 cm in Archaeological Fire Model	65
7.	Archaic Specimens from depths of 2 cm and 5 cm in Archaeological Fire Model	66
8.	Modern Weathered Segments from depths of 0 cm, 2 cm and 5 cm in Forensic Fire Model	72
9.	Modern Weathered Segments Heated in Electric Kiln for 48 hours	81
10.	Archaic Segments Heated in Electric Kiln for 48 hours	82

Chapter I

Introduction

The recovery of burned bone during anthropological investigations provokes numerous taphonomic questions. Identifying fire remnants and determining heating temperature and pre-incineration conditions must be addressed during archaeological investigations of burned bone. The presence of burned bone has been, and continues to be, associated with culinary activities, waste disposal, naturally occurring fires, and crematory practices (e.g., Balme 1980; Buikstra and Goldstein 1973; David 1990).

However, it has been suggested that bone may be burned following burial or deposition (e.g., Binford 1984; David 1990; De Graaff 1961; Lyman 1994; Stiner et al. 1995; Walters 1988). More specifically, post-burial thermal alteration of bone has been put forth by some as a plausible explanation for the presence of burned bone in the archaeological record (e.g., Archer 1977; Degraaf 1961; Lampert 1981; Webb and Snow 1959). This contradicts the assumed chronological relationship between burning and burial and also introduces several additional variables that should be investigated including: sedimentary deposits, duration of heat exposure, and the elapsed interval between burial and exposure to heat.

The accurate assessment of the conditions which result in burned bone are essential to determination of site function. Furthermore, given the role of fire in site formation processes and its association with human activity, archaeologists must consider whether evidence of fire has cultural (intentional) or natural (accidental) origins (Rowlett 1991). In addition, and of particular importance to the study at hand, Rowlett (1991) suggests that the contemporaneity between fire evidence and site formation must be addressed.

The remainder of this chapter will introduce the taphonomic processes that are involved in this hypothesis. In addition, a discussion of fire and burned bone in the archaeological record will be presented.

Taphonomy

One aspect of the study of taphonomy is the examination of artifact assemblages and the subsequent interpretation of their presence and appearance in the archaeological record. An assemblage is a group of artifacts such as modified bone, stone tools or sherds, delimited in time and space. First discussed by Efremov (1940), investigations into the "laws of burial" have generated numerous principals surrounding taphonomic processes. Taphonomic investigations are concerned with interpreting the processes and agents that act between death and fossilization to elucidate a postmortem, post-depositional, and post-burial history (Brain 1981;

Gifford 1981; Lyman 1994). Events that occur during each of these stages directly influence the appearance and the degree of preservation of materials.

The postmortem transformation sequence discussed by Gifford (1981), illustrates the situations by which elements may be incorporated into an archaeological context and the mechanisms that may act upon and transform them. Transformation is caused by a taphonomic agent, which according to Johnson (1985), may be of biological, geological or hominid origin. The mechanism by which modification occurs; "the action of an agent" (1994:3), is defined by Lyman as a taphonomic process. The resulting modification is referred to as a taphonomic trace (Lyman 1994). For example, elements may be modified in a post-depositional context by the actions of carnivores; artifacts may be affected by weathering, trampling, and geochemical processes. Subsequent burial transforms lead to the incorporation of artifacts in a sedimentary (subsurface) deposit where elements may be affected by such processes as fluvial actions, floral development, trampling and geological events. Artifacts may be modified by many agents in a surface or post-depositional context as well as in a sedimentary (sub surface) or post-burial context.

Burial and deposition are separate periods in the taphonomic history of artifacts. Deposition involves placement or location on a surface, whereas burial refers to covering or layering with sediments (Lyman 1994). Burial as a taphonomic process incorporates several factors, specifically: agent of deposition, rate of deposition, depth of burial and type of sediment. Subsequently, thorough

archaeological investigation must incorporate potential alteration induced by post-depositional processes (Stein and Farrand 1985). Often, it is difficult to isolate and investigate these processes due in part to the absence of known signatures of post-depositional processes. Recognition of patterns of modification and identification of causal processes are crucial to taphonomic studies (i.e., the hunting versus scavenging debate). Actualistic investigations (taphonomic models) are experimental analogues through which investigators can make deductions regarding the processes and patterns of bone modification (see Bonnichsen 1989).

Ascertaining depositional and burial histories are an integral part of faunal analysis, and are, in part, reliant upon taphonomic studies. The results of actualistic studies, often conducted in conjunction with ethnographic observations, have generated criteria to better interpret the archaeological record (Bonnichsen 1989). The actualistic replication of post-depositional and post-burial thermal alteration of faunal remains is a study which will provide information to better interpret burned remains recovered archaeologically.

Fire in the Archaeological Record

Ideally, archaeology seeks to generate causal links between the past and material culture. The presence of burned material (i.e., bone, and sediment), is traditionally associated with human manipulation of fire. However, the discovery of burned materials provokes numerous questions, culminating in the more complex

issue of what such evidence indicates about human behavior. As stated by Stiner and coworkers (1995), archaeologists are concerned with the processes by which burned bones are incorporated into the record. To this end, the accurate identification and interpretations of context and recovered materials is necessary.

Bone, particularly burned bone, has direct implications for subsistence, taphonomic, and formational studies (McCutcheon 1992). The effects of fire on bone have been studied by numerous researchers (e.g., Shipman et al. 1984). Laboratory studies have attempted to chronicle specific characteristics associated with differing temperatures (see McCutcheon 1992; Nicholson 1993; Shipman et al. 1984). Replicative experimentation has also focused upon the patterns associated with varied heating situations (see Buikstra and Swegle 1989; David 1990; Thurman and Willmore 1981). Although these studies investigate the patterns associated with heat exposure, further examination is required to more accurately address the processes which result in the identification of burned bone.

Numerous post-depositional and post-burial agents affect and potentially alter bone. Diagenesis and preservation profoundly influence archaeological deposits. Knight (1985) has concluded that the preservation potential of bone is increased after incineration and that differential preservation of calcined bone has been associated with bone density and soil pH. Furthermore, several investigators have found similar surficial characteristics associated with both low temperature heating and diagenesis (Nicholson 1993; Stiner et al. 1995; White 1992). Sillen and Hoering (1993) state

that it is difficult to differentiate between diagenesis and burning associated with camp-fires due to similarities in crystal growth. Although these are crucial areas of research, consideration of the temporal association between fire and material alteration is lacking and deserves greater consideration.

Archaeological Evidence

Although anthropologists disagree about the earliest manipulation of fire, it is commonly held that burned material results from direct human activity (see Brain and Sillen 1988 and James 1989, for review). Controlled fire (intentional burning) is associated with food preparation, garbage disposal, and for fuel and mortuary practices (Buikstra and Swegle 1989; David 1990). David (1990) suggests that bone may be burnt unintentionally by bushfires and as a result of accidental positioning underneath (buried) human camp-fires. As David indicates,

> ...human and non-human agents are responsible for the deposition of bones in the landscape, and both are responsible for converting these initial deposits into new ones (1990:65).

Accurate interpretations of burned bone rely upon the ability to decipher the timing and agent of burning (Lyman 1994).

Ethnographic considerations indicate that heat affected bone may be attributable to the indirect human actions. In viewing contemporary societies, Walters (1988) noted the practices of incorporating previously discarded waste bone

into the hearth area of a subsequent fire, resulting in the post-depositional burning of bone. This theory applies not only to bone.

> It can be appreciated that material such as shells from old middens often become incorporated into such an oven, and are thus mixed inextricably with the charcoal of a fire lit many years, perhaps a decade or a century afterwards (Jones 1980:154-155 cited in Walters 1988:216).

Lampert (1981) noted a higher frequency of burned bone in the sub-unit located directly below the occupational level than in the occupation level at Seton cave, a Kartan site on Kangaroo island off the southern shore of Australia. The lower unit composed of light to medium brown sand is without artifacts but contains faunal remains. No mention is made of scorched or discolored sediment which is traditionally considered indicative of hearths (See Bellomo 1990). Lampert concludes that it is,

> ...possible this [burned bone] results from fires lit during the occupation phase affecting bones that had accumulated there prior to human residence, the extreme thinness of the cultural level making such an interpretation feasible (1981:109).

Similarly, Archer, in his evaluation of burned faunal remains from Puntutjarpa rockshelter concludes that "fires might have been built on a living surface where bones had accumulated" (1977:163).

Stratigraphy suggests that materials incorporated in a sedimentary matrix may be affected by post-depositional processes. This premise is particularly relevant to

investigations of rockshelters and caves which are traditionally associated with human occupations and habitation. Rockshelters and caves are characterized by rapid sedimentation, protection from weathering and both human and non-human occupations (Farrand 1985). Given the restricted space of such shelters and the possibility of cyclical habitation these deposits are particularly sensitive to post-burial alteration.

The plausibility of post-burial burning is not limited solely to cave and rockshelter deposits. At Dickson Mounds, Harn (1980) describes burned skeletal remains which he interprets as questionable cremations. He notes light charring on human bones located directly below an adult burned burial located less than one foot below the mound surface. Though elements were disturbed, Harn states that

> ...uneven charring of the bones and the lack of baked or burned soil is not characteristic of the thoroughness of firing usually associated with aboriginal cremations (1980:59).

He concludes that the burning may be of recent origin. In an analysis of middle Mississippian burials at the Angel site, Schurr hypothesized that

> ...a fire was apparently placed over Burial W11A/21 after both bodies had been placed in the grave, because many of the bones of W11A/21 and the articulated knees of W11A/20 were blackened and charred (1992:314).

Webb and Snow's (1959) account of the Dover mound provides further evidence of bone burned in a sub-surface deposit. Burials 40,41, 42 and 43 "had been covered

with heavy bark and a layer of earth some 9 to 12 inches thick" (Webb and Snow 1959:22). Webb and Snow suggest a fire was placed over this group burial which resulted in

> ...partial cremations of some of these skeletons. Some of the bones were calcined; the remainder were heavily smoked (1959:23).

Caldwell and McCann (1941) describe the presence of one partially charred and one cremated burial found near the center of a ceremonial building. They suggest the individuals were interred while the building was in use, possibly altered by a surface fire (Caldwell and McCann 1941).

The possibility of post-burial transformation is similarly applicable to open sites. Binford contemplates the plausibility of this theory when he states that:

> ...it could be argued that the carbonizing was accidental and occurred by virtue of a fire kindled on top of a previously abandoned and scavenged bone (1984:160).

Recently, Lyman has proposed a more specific view:

> If the stratum in which bones are found is organic rich and charred, and the bones in the stratum are also charred, then it is likely the bones were burned when the matrix in which they are embedded burned. If most of the burned bone specimens in an assemblage are spatially associated with fire hearths, fire pits, and/or concentrations of thermally fractured rock...then it is likely the burned bones were burned by humans, and probably intentionally(1994:392).

The distinction between natural and cultural origins of fire is not always clear. Though hearths are traditionally associated with reddened sediment and burned

artifacts, disagreement exists as to the criteria which unequivocally indicate the presence of hearths and humanly controlled fire (Bellomo 1990, 1991) Moreover, preliminary experimentation by Bellomo and Harris (1990) indicates color change seen in soil below a campfire may not be evident after a period of time. Caldwell and McCann (1941) suggest that although no evidence of a hearth was visible, ethnographic accounts indicate ritual fires may have been built possibly affecting interred burials.

Investigations of various fire scenarios (i.e., campfires, stump fires and grass fires) led researchers to conclude that evidence of grass fires will not survive in archaeological contexts (Bellomo 1991; Bellomo and Harris 1990). Likewise, Connor and Cannon (1991) suggest that the sedimentary evidence of a forest fire is very difficult to recognize. However, Rowlett (1991) claims such fires would have an effect on archaeological materials at or near the surface. David (1990) recognized charring on dry bone situated adjacent to a tree ignited by a bushfire. A study of the effects of prairie fire upon subsurface artifacts resulted in a darkened appearance on 56.7% of bone specimens (Picha et al. 1991). However, these researchers imply that the overall impact of post-burial burning will be negligible on artifacts in a subsurface context. They conclude that the degree of burning of artifacts may be reflective of the natural or cultural processes.

Limited examinations have investigated alteration of subsurface bone deposits (i.e., De Graaff 1961; Stiner et al. 1995). In 1961, De Graaf attempted to replicate the

effects of a primitive hearth on sub surface bone fragments. He recognized heat affected bones at a depth of 12 in (inches) following excavation from below a hearth used daily for seven weeks. Elements located between 4-8 in below the fire revealed considerable charring. De Graaff also claimed that the external morphology of bone from the 2-4 in depth does not indicate evidence of thermal alteration. Experiments conducted by Stiner and coworkers (1995) sought to investigate the insulating potential of soil on buried bones. The degree of burning was determined by evaluation of surface color, by infra-red spectroscopy and HCl organic extraction. Burning to the point of carbonization was recognized on bones buried to a depth of 5 cm. Nine of 17 bones buried at 5 cm were carbonized while 4 specimens were "lightly burned" (1995:231). Less than half of bones buried at 10 cm demonstrated any burning. Although fire temperatures exceeded 900° C, no calcination, partial or complete, was noted on bones buried at 1 cm. The work of De Graaf (1961) and Stiner et al., (1995) clearly demonstrate the need for more systematic and accurate testing of post-burial thermal alteration.

Project Aims

The goal of this research is to objectively explore the possibility that bone may be thermally altered in a post-burial setting. Analysis of recovered bone must incorporate results related to degree of burning and temperatures achieved through laboratory examination. To accurately address the plausibility of post-burial burning,

this study will incorporate actualistic and laboratory experimentation. Specific goals are as follows:

1. Can bone be thermally altered in a subsurface (i.e., post-burial) context?
2. Can Archaic bone in deposits dated to 5000 BP be burned in a present day subsurface context?
3. If so, is it possible to distinguish between bone burned in a subsurface (indirect exposure) context and bone burned in a surface (direct exposure) context?
4. How does the intensity and duration of exposure to heat affect the degree of burning?
5. Is the degree of post-burial thermal alteration affected by the composition of the deposit in which an element is located?

Chapter II

Literature Review

Introduction

Traditionally, investigations involving burned bone have focused upon two fundamental points; recognition of heat alteration and the determination of burning relative to deposition and burial (Lyman 1994). Contained within these basic concepts are numerous related themes which have characterized research during the last fifty years. Specifically, investigations, both laboratory and replicative, have focused upon developing criteria for identifying and assessing the degree of heat alteration through classification of color variation (i.e., McCutcheon 1992; Nicholson 1993; Shipman et al. 1984). Research has also focused upon recognizing change in surface morphology, (i.e., fracturing and shrinkage), towards determination of pre-incineration condition (i.e. Buikstra and Swegle 1989; Thurman and Willmore 1981). In addition, microscopic and crystalline structure investigations have been conducted on burned bone (i.e. McCutcheon 1992; Nelson 1992; Shipman et al. 1984). As a result of these macroscopic and microscopic examinations additional questions have been generated regarding duration of heat exposure, post-burial or accidental burning,

and determination of low temperature heating (see Stiner et al. 1995 for review). It is these issues that are the focal point of this research.

An explanation of the basic properties of bone, and the physical and chemical alterations that result from thermal alteration is necessary for an understanding of past, present, and future research.

Bone Structure and Chemistry

Bone, performs several specialized functions in mammalian species: support, locomotion, protection of soft tissues, and regulation and production of mineral constituents (Shipman et al. 1985; Hildebrand 1995). Comprised of specialized cells, bone is continuously remodeled throughout the organism's lifetime (Bloom and Fawcett 1979). Morphological results of external stressors are attributable, in large part, to the structure of bone material. Therefore, an understanding of the gross and histological structure and physiology of bone is a prerequisite for discussing morphological modification and microstructural alteration of thermal affected bone.

Gross Structure

Two types of bone tissue are readily distinguishable, macroscopically: cortical and cancellous. Cortical or compact bone covers the external surfaces and comprises the diaphyses of long bones. Highly vascularized cancellous bone consists of marrow containing cavities known as trabeculae.

Microstructure

Mature bone, both compact and cancellous, is composed of highly organized collagenous microfibril bundles deposited in layers (lamellae) (Stout 1989). This structured tissue is referred to as lamellar bone. The basic unit of lamellar bone is the Haversian system, or osteon, consisting of 4 to 20 lamellae (Bloom and Fawcett 1979). Immature bone is categorized as woven, laminar, or fine (Shipman et al. 1985) and is the precursor to mature bone as it appears during embryonic development (Vaughan, 1970). Less organized in its structure, it appears coarse and fibrous with random and irregularly oriented collagen fibers.

Non-human bone is predominantly comprised of coarsely bundled bone; woven or parallel, though it lacks a true lamellar structure (Pritchard, 1956). Deer bone is characterized as plexiform bone, a primary symmetrical network of bone. Plexiform bone is comprised of parallel segments of bone interspersed by vascular canals (George 1995).

Bone Cells

There are three types of bone cells which, are continuously engaged in bone remodeling. Osteoblasts and osteoclasts are responsible for the formation of new and resorption of old bone, respectively. Osteocytes are actively involved in the mineralization and maintenance of bone tissue (White 1991). Basically, osteoblasts,

as the primary bone forming cells, secrete unmineralized osteoid that forms a collagenous matrix. These cells become surrounded by mineralized bone following the deposition of hydroxyapatite. Isolated osteoblasts differentiate into osteocytes and maintain bone tissue.

Molecular Composition

Bone tissue possesses a distinct chemical composition that is similar among mammals. Regardless of species, bone consists of organic and inorganic components. Collagen, the organic matrix, is a protein that occurs in long fibrils and provides elasticity, flexibility, and strength to bone. Ninety percent of bone matrix is comprised of this Type I collagen (see Shipman et al. 1985; Vaughan 1970). Calcium salts, primarily hydroxyapatite, ($Ca_{10}(PO_4)_6(OH)_2$) are deposited in crystals and as they grow, they promote rigidity and hardness as the inorganic component of bone (Shipman et al. 1985). Electron microscopy of non-human bone demonstrates

> ...apatite particles are needle-shaped, 30-60 A (angstroms) in diameter and aligned along the collagen matrix (Fernandez-Moran and Engstrom 1957:263).

The relationship of these two materials changes during maturation. At death, the percentage of crystallinity increases (Posner 1969). Although collagen is resistant to decay, following death the remaining organic component decomposes (Chaplin 1971).

Thermal Alteration and Bone Structure

The presence of inorganic and organic components render bone a strong and highly resilient tissue. Exposing bone to heat alters this relationship and produces a series of macroscopic and microscopic changes. Heat dehydrates and denatures bone, which results in gross distortion as water molecules are extracted from both the organic compounds and the hydroxyl bonds in the hydroxyapatite crystals (Shipman et al. 1984). Exposure to heat generates sequential change in the color of bone: to brown, dark brown and black, to blue gray and white. Dark colors are attributed to the incomplete combustion of the organic material, while white colors are associated with the complete incineration of the organic component.

Structural modification that results from low temperature heating [under 500° C (centigrade)] has been virtually ignored in the scientific literature. However, Richter (1986) demonstrated that morphological changes do occur in bone collagen heated to 60° C and 80° C. The extraction of collagen dramatically increases the fragility of bone. Thermally altered bone is brittle due to the sole presence of the inorganic component. However, the remaining crystalline structure retains the gross contour. Furthermore, the microstructural integrity of bone is, to a certain extent, affected by heat (Bloom and Fawcett 1979).

The microstructural response of bone to heat is not entirely understood. Experiments by Kiszely (1973) indicate that 500^0 C marks the upper limit for the

escape of organic substances. Carlstrom and Finean, in a x-ray diffraction study of fish bone concluded that heating to 500° to 600° C "seems to cause a fusion of the crystalites" (1954:190). They add that this may result from minimal chemical change in the apatite structure. Shipman et al., (1984) found that bone heated above 645° C becomes characterized by an increase in hydroxyapatite crystal size in compared to bone exposed to temperatures less than 525° C. Gruppe and Hummel (1991) report that residual carbon from organic components is burned off between 600° and 700° C. According to Shipman et al., (1984) temperatures in excess of 800° C are associated with fusion or melting of these crystals.

Size modification resulting from heat exposure has been addressed by several researchers (i.e. Gilchrist and Mytum 1986; Herrmann 1977; Shipman et al. 1984). Histological investigations by Herrmann (1977) suggest that at temperatures above 700°-800° C cremation (complete combustion) of organic matter and fusion of bone mineral occurs which leads to shrinkage of the bone. Shipman et al. (1984) recognized variation from 2-3% up to 15% at temperatures in excess of 900° C. Conducting campfire experiments, Gilchrist and Mytum (1986) noted a decrease in size with mean shrinkage of 5.8% for femora and 32.9% for ribs. These investigators attribute this disparity to varying ratios of compact to spongy bone between the non-human elements used in the experiment. Understanding the potential for size modification of burned bone is important in both human and faunal analyses.

Gifford-Gonzalez (1989) recognized a similar appearance on heated bone specimens and weathered specimens. White (1992) further notes the resemblance between low temperature burning and diagenetically induced surface erosion and recrystallization. Nicholson, (1993) echoes this view as she states that burning may superficially imitate weathering. Experimentation by Stiner et al. (1995) indicate that recrystallization (increase in apatite crystal size) of burned bone is similar to the recrystallization associated with weathering. They conclude that changes induced through natural exposure partly overlap those crystalline changes witnessed on bone heated to the stage of carbonization. Recognizing potentially similar signatures of diagensis and heating is crucial for accurately interpreting bone assemblages.

Burned Bone Research

Early examinations of burned bone arose out of a desire to interpret archaeological and paleoanthropological evidence. In an early study, Franchet (1934 cited in McCutcheon 1992) recognized eleven stages of burned bone classified by color and macroscopic morphological attributes. In the years following, reports by Haury (1945), Webb and Snow (1945) and Angel and Coon (1954) led to an increasing pool of information on thermal alteration of bone. However, it was not until 1954 when Baby published his preeminent work on Hopewell cremation practices that investigations of burned bone addressed analytically based mortuary questions.

Crematory Investigation and Pre-incineration Condition

Early studies were concerned with establishing criteria to permit demarcation between cremations of dry versus fleshed bone. Although the primary aim of Baby's (1954) research was to decipher Hopewellian mortuary treatment of the dead prior to cremation, his work continues to influence anthropological research today through a three way classification of burned bone.

> (1). Completely incinerated. Fragments range from light gray, blue-gray, to buff in color, and show deep 'checking', diagonal transverse fracturing and warping.
> (2). Incompletely incinerated, or 'smoked'. Fragments blackened in color from the incomplete combustion of organic material present in bone.
> (3). Non-incinerated, or 'normal bone'. These fragments were not affected by the heat, but do show some smoking along broken edges (Baby 1954:2).

He attributed the varied appearances of burned bone to the duration of exposure and the proximity of bone to fire. Though later faulted for an ambiguous description of his experimental sample, (see Thurman and Wilmore 1981, for a review) as an archaeologically relevant and experimental work, Baby's research greatly advanced the study of burned bone. His conclusions generated several avenues of further research, specifically, greater recognition of stages of burning, pre-incineration condition, in-situ cremations, and an attempt to associate burning patterns with specific temperatures.

Wells (1960) initiated the formal analysis of cremation by documenting the affects of cremation and suggesting that degree of distortion was related to firing temperatures and living size. Binford (1963), continued cremation experimentation through his analysis of late Archaic burial sites in Michigan. His comparative analyses echoed earlier findings suggesting that it is possible to differentiate between dry and fleshed cremations.

> Dry bone tends to show predominantly longitudinal fractures, an absence of warping, and superficial angular cracking; cremations of green bone or bone with the flesh attached show deep transverse fractures, frequently curved, much warping (1963:102).

Binford reached several pertinent conclusions regarding the degree of burning by recognizing not only the role of duration and intensity of the fire, but also the position of the bone in addition to pre-incineration condition.

Cremation investigations demonstrated the ability to differentiate between the pre-incineration stage of bone based upon fracture patterns (see Ubelaker 1989). A secondary aim was to understand the degree of morphological distortion as it has direct implications for estimation of demographic characteristics (Gejvall 1963; Merbs 1967). Although these researchers recognized the role of intensity, duration, and proximity to fire, they neglected to investigate specific temperature related changes. These early investigations, though beneficial, relied almost solely upon

subjective visual description. Hence, the information generated was insufficient to address archaeological questions regarding burned bone and human activities.

Laboratory Experimentation

During the last decade, researchers have turned to the laboratory to investigate burning parameters in more controlled settings (McCutcheon 1992; Nicholson 1993; Shipman et al. 1984). Laboratory experimentation has focused upon several aspects of burned bone: surface color, macroscopic morphology and microscopic crystalline structure. The work of Shipman et al. (1984) has provided a foundation for controlled investigations of burning using a muffle furnace to accurately record temperatures. Fresh bone specimens were heated for 4 hours to reach maximum temperature and then cooled for the same period of time. Shipman and coworkers (1984) investigated the effects of controlled heating, up to 940 ^{0} C, upon color, microscopic morphology, overall size and crystalline structure. Subsequent research has replicated their work and generated an increasing body of information on burned bone (McCutcheon 1992; Nicholson 1993).

Color

Surface colors have been used to characterize exposure temperatures. Shipman et al. (1984) standardized description of surface colors on burned bone by using Munsell Soil Color Charts (Munsell Soil Company Inc. 1954) to record

dominant and secondary colors. Heated bones display a variety of colors, with one color traditionally covering a larger portion of the surface (dominant). Numerous secondary colors may appear across the surfaces. Changes in color were found to correspond to five stages associated with specific temperature ranges (Shipman et al. 1984) (see Table 1).

Table 1: Five stages of heating temperatures and associated colors as determined by Shipman et al. (1984).

Stage	Temperature	Description
Stage I	20 -<285 C	neutral white, pale yellow and yellow
Stage II	285-<525 C	reddish brown, very dark gray-brown neutral dark gray, and reddish-yellow
Stage III	525-<645 C	neutral black, with medium blue and reddish-yellow
Stage IV	645-<940 C	neutral white, with light blue-gray and light gray
Stage V	940 + C	neutral white with medium gray and reddish-yellow

Assessment of surface color is affordable and practical, though Shipman et al. claim, the method is imprecise as a sole indicator for estimating maximum heat exposure. Bonucci and Graziani (1975) concluded that bone color could be used to deduce approximate heating temperatures. Nicholson, however, suggests the assessment of temperature from surface color provides a "crude estimate of around ±

200°C" (1993:415). Recently, Taylor and coworkers (1995) found in a review of archaeological site reports, that surface color was the sole criteria used in assessment of thermal alteration of bone. Based upon a study of Pueblo II Period bone, they also concluded that classification of bone based on surface discoloration is an accurate indicator of thermal exposure. McCutcheon (1992) combined the assessment of color with microscopic and structural criteria in a three-class system for estimating exposure temperatures (see Table 2). Slight variation in colors and associated temperatures are apparent between researchers because of the subjective nature of this exercise.

Microscopy

Scanning electron microscopy (SEM) has, not suprisingly, resulted in the even recognition of greater morphological variety (McCutcheon 1992; Nicholson 1993; Shipman et al. 1984). Analysis of goat and sheep bone by Shipman and coworkers (1984) revealed five temperature related stages (see Table 3) which do not coincide exactly with the temperature stages associated with surface color (see Table 1). Although the use of SEM provides highly magnified black and white images of surface topography, unfortunately, this is a procedure that has not been available to, or employed by, all researchers studying these structures.

Table 2: Three classes of heating temperatures and associated colors, SEM and x-ray diffraction as determined by McCutcheon (1992).

Class	Temperature	Description
Class I	185-<340 C	range-pale brown to black to pale brown minimal increase in surficial porosity Poorly defined diffraction pattern
Class II	440-<600 C	light brownish gray to white marked increase in porosity distinct diffractograms
Class III	650-<950 C	white aggregates poorly defined, globular diffraction patterns indicate large crystal size

Table 3: Five stages of heating temperatures and associated microscopic morphology as determined by Shipman et al. (1984).

Stage	Temperature	Description
Stage I	20 -<185 C	normal bone texture is present...surface intact and continuous.
Stage II	185-<285 C	the bone surface becomes more irregular as small granular asperities separated from one another by tiny pores and fissures appear.
Stage III	285-<440 C	bone surface becomes glassy and may take on a vitirifed appearance.
Stage IV	440-<800 C	bone surface becomes highly particulate ...and rapidly turns frothy.
Stage V	800-<940 C	frothy particles melt and coalesce into larger structures.

Nicholson (1993) categorized burned bone into four stages combining SEM with macroscopic assessment and optical microscopy (see Table 4). Standard optical, or light, microscopy is an available and affordable technique for evaluation of microstructure. Nicholson (1993) suggests this technique is useful for analyzing bone heated to temperatures less than 700° C.

Table 4: Four stages of heating, color and associated microscopic morphology as determined by Nicholson (1993).

Stage	Temperature	Description
Stage I	200-300 C	strong brown undulating surface with vascular canals
Stage II	300-400 C	black peeling layer over granular surface with vascular canals
Stage III	400-600 C	grey, light grey polygonal cracking, pitted and granular, edges of cracks curling upward
Stage III/IV	700 C	white articular surfaces variable coloring pitted, granular and smooth surfaces
Stage IV	800-900 C	white smooth surface, less prominent canals

A review of laboratory research demonstrates marginal differences exist between researchers. By controlling temperatures, these experiments have focused upon recognizing criteria associated with specific temperature ranges. It is possible to apply these characteristics to estimate maximum heating temperatures of bone.

Laboratory experimentation of burned bone has generated a general scheme of traits to make inferences about maximum heating temperature correlated to morphological change. However, the sole application of laboratory results to archaeological analysis of burned specimens is unfruitful. Specifically, this criticism is true for burned bone studies which necessitates experimentation with fires as opposed to furnaces. Research must incorporate replication of the natural processes that created the burnt bone.

Replicative Experimentation

Several researchers have conducted replicative investigations of burned bone. This approach seeks to investigate parameters of burning in a less controlled, though more actualistic setting. A cremation experiment conducted by Thurman and Willmore (1981) upon human cadavers expanded upon earlier studies (i.e., Baby 1954; Binford 1963) and subsequently generated a more universal syntax. Thurman and Willmore suggested that in-flesh cremations are characterized by

> ...serrated, transverse fractures totally through cremated bone along with diagonal cracking accompanied by warping (1981:281).

In contrast, burned "green" (greasy and recently defleshed) bone was found to demonstrate

> serrated fractures near epiphyses but otherwise parallel-sided fractures through bone (along checking lines), and less pronounced warping (1981:281).

Buikstra and Swegle (1989) investigated the pre-incineration condition of mammalian bone subjected to open fires in excess of 800 ° C. Analysis of surface color and fracture patterns suggest it is possible to differentiate between bone burned dry, green (recently defleshed) and burned with flesh covering. They indicate that number and not type of fracture indicate pre-incineration condition. Buikstra and Swegle (1989) note the presence of warping in burned dry bone. They note heat affected dry bone demonstrates less extreme colors. "Dry femora assumed a light brown or tan color" (Buikstra and Swegle 1989:252).

Gilchrist and Mytum (1986) analyzed color change, shrinkage and maximum temperatures attained in hazel and ash wood fires reporting fire temperatures ranging from 700° - 800° C. Fresh bone was periodically removed for assessment at temperatures from 200°-700° C. Surface colors coincided with those noted by Shipman et al. (1984) for stages I, II and III. They note that bone is often stained by sediments which confounds surface color assessment of burning.

Spenneman and Colley attempted to replicate accidental burning of bone discarded in pits and hearths. Experimental bone included "dried out and bleached" faunal material and "dried out and stained by soil" human bone (1989:59). They recorded both distortion and rough-edged breaks along the longitudinal axis on the sheep and goat femora. They report that these fractures are easily distinguished from those witnessed in fresh bone, though they claim weathered bone that has been burned demonstrated no variation in surface texture.

Replicative experimentation attempts to simulate the conditions that generated archaeological materials. Though the relationship between burned features and temperatures is more ambiguous, investigation into the actualistic conditions that result in burned bone is necessary.

Conclusions

Numerous controlled burning experiments indicate pre-incineration condition, duration of exposure, and intensity of heating affect the condition and appearance of burned bone. Identifying criteria of fracture patterns, surface color, macroscopic morphology and microscopic structure have been associated with certain heating situations. A review of the literature surrounding burned bone has several implications for the study at hand. First and foremost, it generated a list of traits and characteristics with which to compare the results of the present investigations. Second, a critique of previous studies prompts questions for incorporation into this and future research endeavors. The use of replicative experimentation incorporating a high degree of temperature control appears to be the ideal mechanism for investigating burned bone. Subsequent analysis must incorporate assessment of surface color, macroscopic and microscopic morphology.

Chapter III

Materials and Methods

Introduction

Two replicative experiments were conducted to test assumptions of subsurface thermal alteration. Buried skeletal elements of whitetailed deer, *Odocoileus virginianus*, were exposed to an indirect heat source to replicate post-depositional alteration. A comparative sample was prepared following the heating procedure utilized by Shipman et al. (1984).

Modern weathered bone and archaeologically-recovered (Archaic) bone were used in the first experiment. Bone was buried at incremental levels below surface campfires in the archaeological fire model. In a second experiment, the forensic fire model, modern weathered bone was buried in the crawl space of a single story house prior to incineration of the entire structure. The utilization of different firing situations provides an opportunity to address several variables. Specifically, the role of duration and intensity of exposure was investigated. Fire and subsurface temperatures were recorded throughout the experiments to show trends in the subsurface radiation of heat. Upon excavation, the bone was analyzed to determine patterns associated with subsurface exposure.

Material

Both modern weathered and Archaic specimens of whitetailed deer were used in this study. Whitetailed deer was used as it constitutes a large portion of the identified faunal material in archaeological assemblages in eastern North America. Results are applicable to other faunal materials as the macro and micro structural characteristics of mammalian bone are similar.

Modern Bone Sample

The modern bone sample consists of weathered whitetailed deer metapodial segments. Complete bones exhibiting characteristics of late stage (1) and early stage (2) weathering, as described by Beherensmeyer (1978), were collected during the fall of 1994. This classification is based upon the presence of longitudinal cracking, splitting lines and flaking of the outer surface (Beherensmeyer 1978; Johnson 1985) (see Plate 1) The degree of weathering is indicative of the duration of exposure to natural agents and can occur in subaerial (surface) and subsurface contexts (Beherensmeyer 1978; Lyman 1994). The use of slightly weathered bone is necessary for accurate post-depositional experimentation as burial is associated with arrested weathering (Lyman and Fox 1989).

Collected elements were rinsed to remove any residue and were curated in an outdoor environment prior to use. Similarly sized metapodials were selected for



Plate 1: Late Stage1, Early Stage 2 (after Beherensmeyer 1978), Sectioned Modern Metapodial.

inclusion in the project. Preparation of specimens involved longitudinally bisecting each metapodial using a stryker saw. Each half was then cut into proximal, middle and distal sections. Five metapodials were prepared in this manner. The segments were used in both archaeological and forensic fire treatments. Proximal and distal segments were exposed to heat while middle segments were unburied controls. Three metapodials sectioned in this manner were used in the laboratory experiment. Here middle, proximal and distal segments were exposed to heat.

Archaeological Bone Sample

The archaeologically-recovered (Archaic) bone was selected from a single 1meter x 1meter x 10 centimeter excavation unit (988 N 920 E- level 19) in a late Middle Archaic archaeological horizon at the Hayes site (40 ML 139), a stratified Archaic midden on the Duck River in central Tennessee. The sample consists of thirty-two similarly-sized bone fragments of whitetailed deer dated to approximately 5500 BP. These specimens demonstrate extensive cracking and exfoliation of cortical surfaces reflecting an extended period of exposure. This sample is required for an actualistic investigation of post-burial heat alteration.

Laboratory Comparative Sample

Specimens of modern weathered bone and archaeological bone were heated in a controlled setting, i.e. known temperature, using a Skutt 240 amp. electric kiln (model

1227) under the direction of Dr. J. Darrow of the Art Department; ceramics studio at the University of Tennessee (see Figure 1). The internal chamber dimensions are 68.5 cm x 68.5 cm with temperatures regulated for each of three zones. Rate of heat increase, maintenance of temperature and rate of cool down were controlled by the experimenter. Heat is uniformly distributed throughout the kiln, resulting in even heating of bone specimens. Following the procedures of Shipman and coworkers (1984), bone specimens were heated for four hours and allowed to cool prior to removal from the kiln. A segment of modern metapodial and a fragment of Archaic bone were heated simultaneously situated on a shelf suspended in the center of the kiln.

Temperatures were monitored using a Thermolyne Sybron type PM 20700 digital pyrometer capable of reading temperatures from -50 ^{0}C to 1300 ^{0}C. The probe of the pyrometer was inserted through a temperature chamber and extended into the kiln directly above the bones. Temperatures were verified hourly during each procedure. A modern and an Archaic specimen were heated to each of the following temperatures: 220° C, 330° C, 410° C, 520° C, 620° C, 710° C. Temperatures are within a $\pm$ 5-10° range. These temperatures approximate those utilized by Shipman et al. (1984), McCutcheon (1992) and Nicholson (1993). Modern weathered specimens are segments of a single metapodial sectioned into distal, proximal and middle portions. This controlled heating process generated a sample of both modern weathered and Archaic bone heated to known temperatures. These bones were compared with results reported by previous researchers and specimens burned during actualistic investigations.

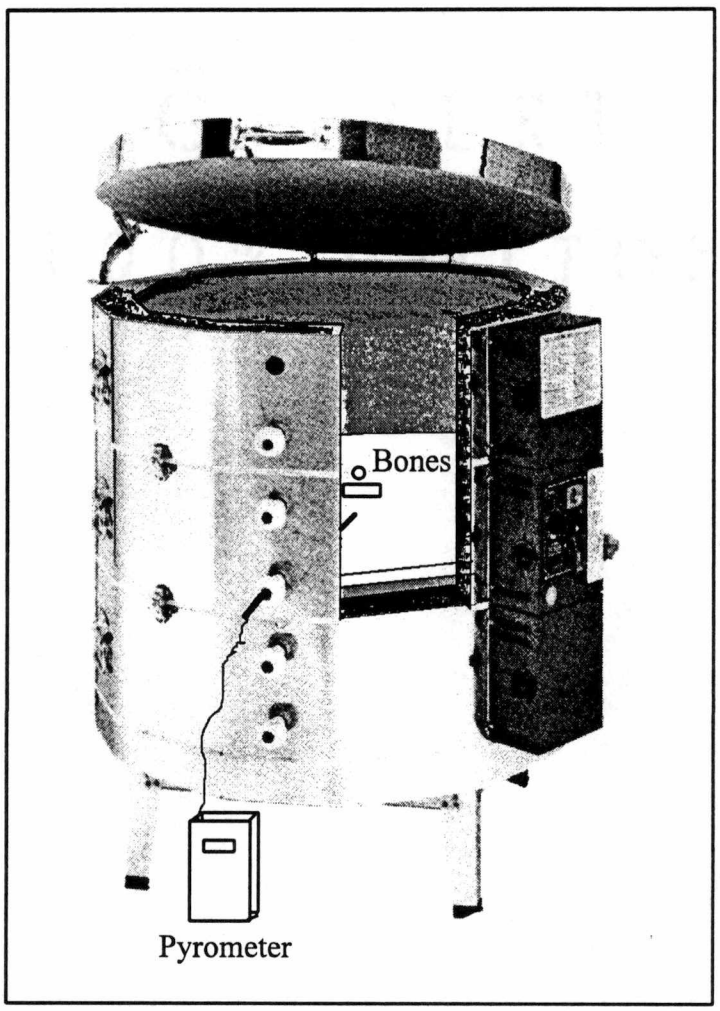


Figure 1: Skutt Electric Kiln, model 1227 (after Skutt Ceramic Products 1986).

Archaeological Fire Model

The archaeological fire model was designed to replicate a prehistoric occupational campfire. This experiment is comprised of two identically prepared fire simulations. Each consists of a burial unit and a temperature recording chamber separated by sedimentary bulk.

Two burial units, (30 cm x 30 cm) were prepared. These units were located approximately one meter from each other. A rectangular pit approximately 60 cm x 25 cm was excavated fifteen cm from each burial unit. These temperature chambers facilitated insertion of a pyrometer for measurement of temperatures in the subsurface levels (see Figure 2). Each temperature chamber was separated from the burial unit by a 15 cm wide earthen bulk. Three holes were drilled through this bulk at 5 cm, 10 cm and 15 cm below the original surface. Subsurface temperatures were recorded at each depth. Ceramic insulators were placed in the wall of each unit at these locations to permit accurate insertion of a digital pyrometer for temperature readings.

Each burial unit consists of six incremental levels. The uppermost is located 2 cm below the surface with the remaining five located at 5 cm, 10 cm, 15 cm, 20 cm, and 25 cm below the surface (see Figure 3). Two bones, one modern metapodial segment and one fragment of Archaic bone were buried at each level in both units. Bones in adjacent levels were positioned at 90 degree angles to allow even exposure to radiating heat. Modern distal bone fragments were buried in one unit. Modern proximal

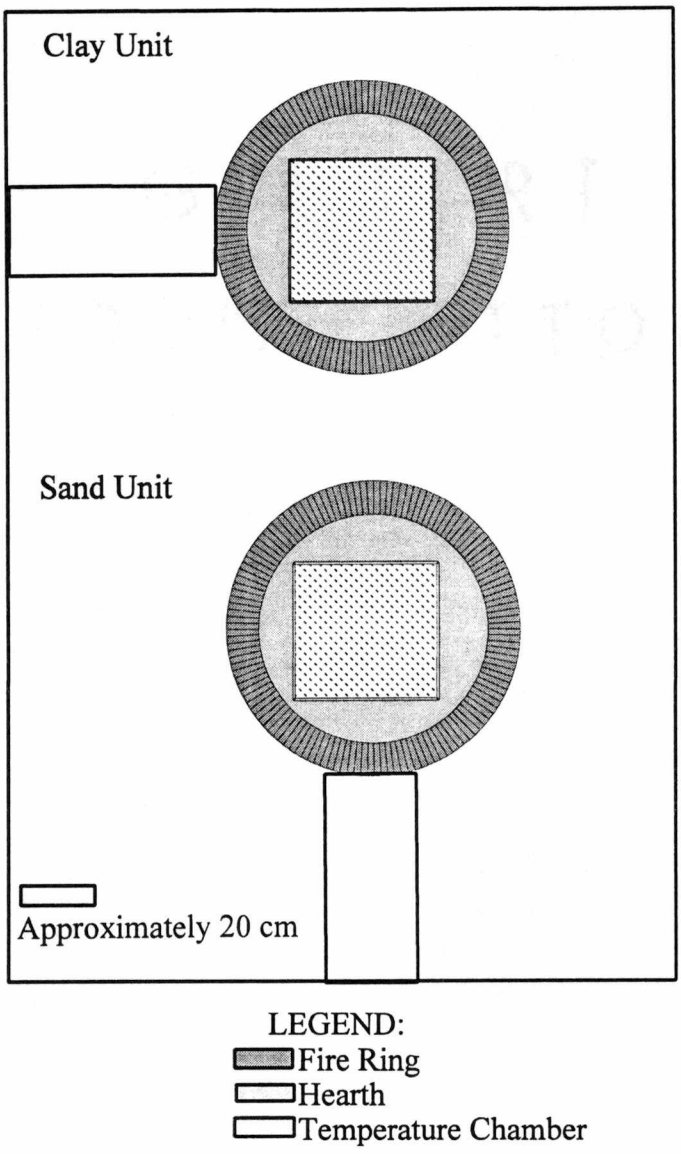


Figure 2: Superior Schematic of Units in Archaeological Fire Model.

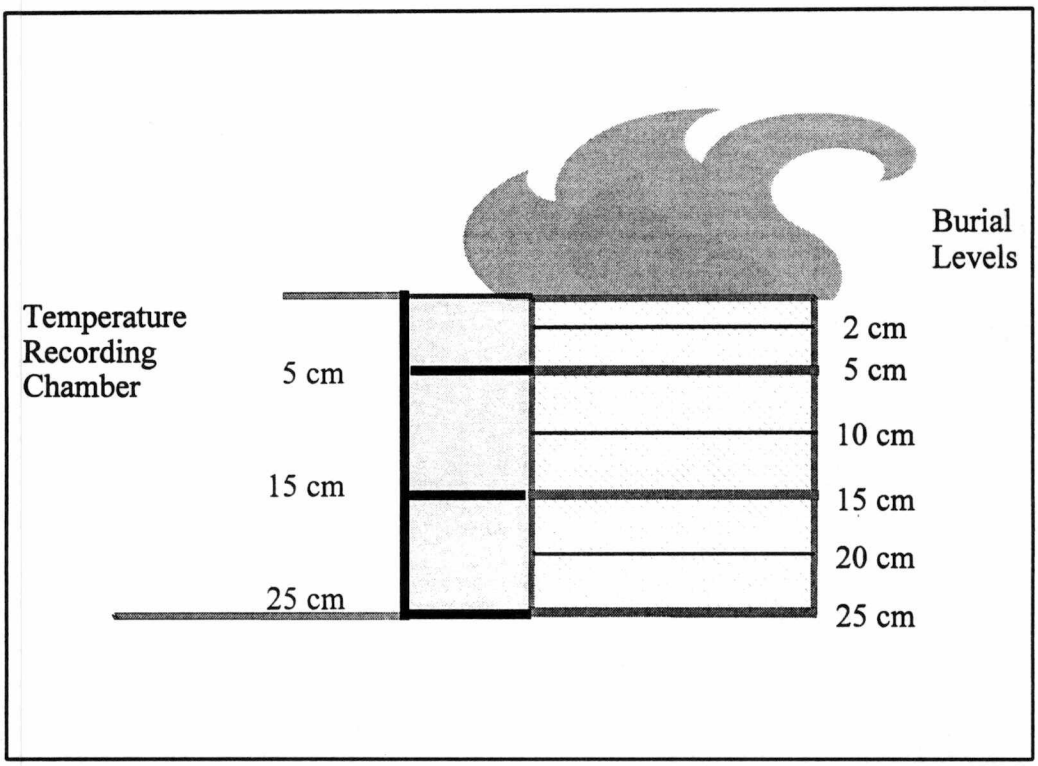


Figure 3: Profile Schematic of a Unit in Archaeological Fire Model

fragments were buried in the other unit. Segments cut from the same bone were buried in adjacent levels.

Burial units were not refilled with the local soil. One burial unit was refilled with dark reddish-gray clayey- silt. The sediment was sifted through ¼ inch screen to remove any rocks and debris. Each level was compacted as it was buried to eliminate any air pockets. The second burial unit was refilled with a fine grain, pale yellow sand. Samples of both sediments were collected and subjected to a particle size analysis. The use of different soils permits investigation of the conductive properties of varied sediments.

Stone hearths, with an internal diameter of 45 cm were built above each unit. Fires of red cedar (*Juniperous virginiana*) were maintained above each burial unit for forty-eight hours. Subsurface temperatures were recorded throughout the experiment using a Thermolyne Sybron type pm 20700 digital pyrometer. A NiCr-NiAl thermocouple is effective in recording temperatures from -50 °C to 1300° C.

All temperature measurements were taken by completely inserting the probe of the pyrometer through the bulk into the subsurface matrix. The probe extended into the center of the level in proximity to the bone and directly under the fire. The pyrometer was maintained in this position until a constant temperature was reached. Temperatures were recorded in Celsius to the nearest tenth of a degree.

Initial subsurface temperatures were recorded for both units prior to commencement of the fires. Temperatures were recorded hourly at each of the three

zones in both burial units. A total of forty-six hourly temperature readings were taken during this experiment. Forty hourly temperatures were recorded during the initial forty-eight hours of the study. The temperature of the fires were recorded at the twenty-fourth hour of the experiment. Following the initial forty-eight hours of fire maintenance no additional wood was added. Temperatures were then recorded at twelve hour intervals to measure the rate of decreasing temperature. Seven days after the experiment was conducted the units were excavated.

Several calculations were performed on the recorded temperatures to reflect the periods of heating, maintenance and cooling, and to facilitate subsequent discussion of heat transfer in sediments.

Forensic Fire Model

This phase of the investigation was conducted in conjunction with the Knox County Task Force under the direction of Mike Dalton. Members of the task force, as part of routine training, were responsible for the complete incineration of an abandoned house in Powell, Tennessee. The residence measured approximately 950 square feet in area. Windows and doors were intact and the interior of the house (i.e., furnishings) was arranged to replicate an inhabited dwelling.

Modern weathered metapodial segments were buried beneath the single story frame house on Wednesday, November 29, 1995. Two small units measuring 15 cm x 15 cm were excavated to a depth of 5 cm below the crawl space floor. These units were

separated by a distance of 0.5 m (see Figure 4). Distal modern segments were buried in Unit A at depths of 5 cm and 2 cm. Bones in adjacent levels were positioned perpendicular to the specimens located above and below. Proximal segments were interred in similar manner in Unit B. Middle sections were not exposed to heat.

A Bell Research Pyro mini bar was suspended between two small clay spheres in each burial level to indicate the maximum temperature attained at that depth. The units were refilled with local sediment, a subsoil clay with limestone gravel. In addition, two segments were placed on the surface. Four Orton standard pyrometric cones consisting of a firing cone, two guide cones, and a guard cone were embedded in a clay patt following the procedures set forth in the Orton (1984) manual. This device was placed on the surface to provide an estimate of the maximum temperature. Post incineration interpretations of the pyrometric cones were made with the assistance of a member of the Art Department at the University of Tennessee. Estimates of the average burning temperatures in each room of the house were calculated by David J. Icove of the Tennessee Valley Authority and University of Tennessee Engineering Department.

On Saturday, December 2, 1995, a fire was started in the room located directly above the experimental area. The fire was ignited by members of the Knox County Task Force. Steel wool soaked in gasoline was placed in an operating microwave oven. The combustion of this appliance was insufficient to ignite the room and a second fire

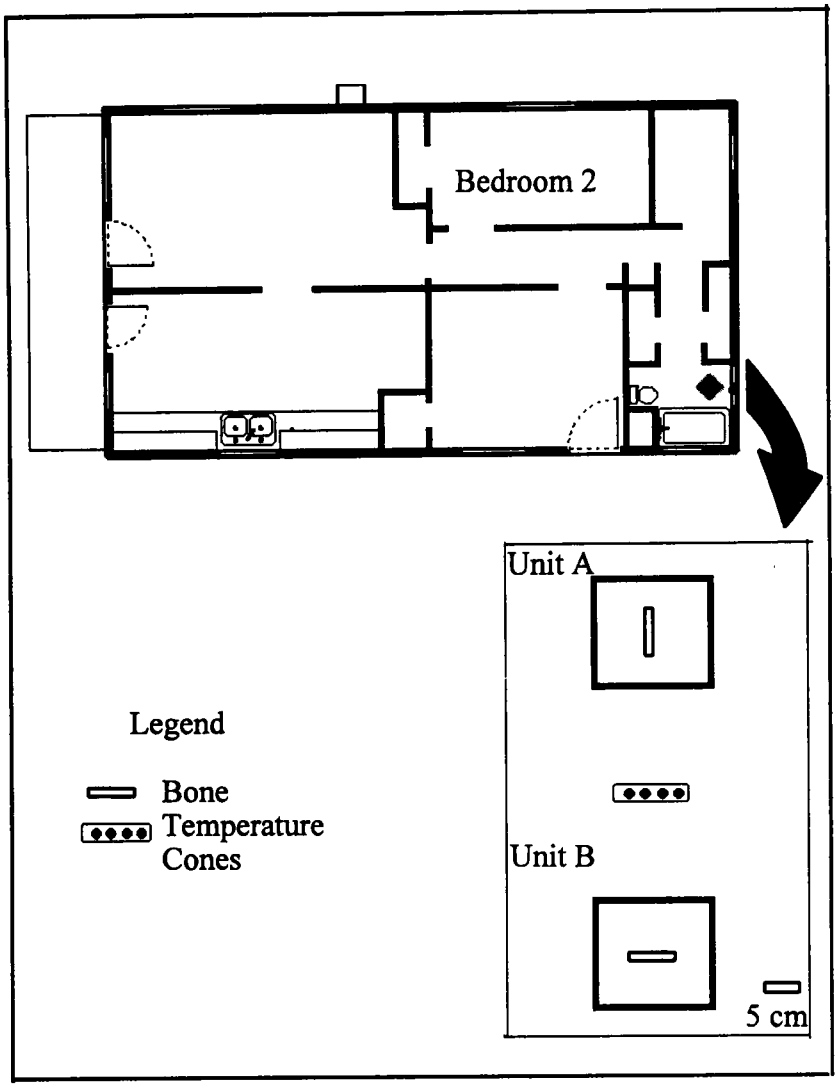


Figure 4: Floor Plan of Single Story House with Highlighted Aerial Schematic of Forensic Fire Model

was begun in bedroom "2" using gasoline (see Figure 4). The fire was permitted to burn without interference (i.e., the application of water) by Rural Metro firefighters. The time from activation of the microwave to complete reduction of the structure was recorded by Mike Dalton, as well as estimation of smolder time and time until cessation of heat radiation. Excavation and recovery of the metapodial elements was conducted on Monday, December 4, 1995.

Excavation and Recovery

All units were excavated using standard archaeological procedures. The depth of the ash layer was measured and removed to expose the surface. The sediment was gently removed using a trowel and small brush to expose the faunal material. All specimens were photographed *in situ*. The physical appearance of the sediment was noted and color variations recorded using the Munsell Soil Color Chart (Munsell Soil Company Inc. 1954). Recovered segments were placed in separate paper coin envelopes and labeled to reflect unit and depth. Specimens were transported to the University of Tennessee for analysis.

Temperature Estimation

The maximum temperature reached and mean temperature ranges were calculated for each level in the archaeological fire model. Maximum temperatures

attained at each level in the forensic fire model were estimates. Determination of the subsurface temperatures is crucial to the accurate investigation of post-burial alteration by heat by providing a comparison with results achieved in laboratory examinations. In addition, this data is necessary for investigation of the radiation of heat through the soil matrix.

Macroscopic Evaluation

All specimens were subjected to the same macroscopic evaluation to investigate the relationship between heat exposure and physical appearance. Faunal elements were brushed to remove any sediment. Fifty-nine specimens were analyzed (see Table 5).

Table 5: Totals of Bones used in Investigation.

	Number heated	Number unaltered "controls"
Archaic Specimens	21	2
Modern Distal Segments	12	0
Modern Proximal Segments	12	0
Modern Middle Segments	3	9
Total	48	11
Sample Total	59	

The macroscopic analysis of specimens involved determination of color, assessment of fracture patterns and evaluation of warping. Bones were classified using criteria generated by replicative and laboratory experimentation.

Color

Color analysis of specimens involved an initial classification followed by assessment of surface color. Variation in surface color assumes differential exposure to heat. Surface colors, primary and secondary, evident on all specimens were evaluated using the Munsell Soil Color Chart (Munsell Soil Company Inc. 1954).

Fractures

All specimens were assessed for distortion of morphological attributes, i.e. fracturing. Fractures were evaluated and categorized as: transverse, longitudinal and or splintered. The location of fractures was also recorded.

Warping

The degree of warping was assessed for all specimens and subsequently classified as: absent, minor, moderate, or severe

Microscopic Examination

A complete analysis of heat modification necessitates microstructural evaluation. Variation in the external surface structure was investigated using a standard light microscope as such are usually available.

Stereomicroscopy

All specimens were examined using a standard, reflected light dissecting stereomicroscope (Olympus SZH10) located in the Department of Anthropology. Photomicrographs were taken using an attached Olympus 35mm camera and T160 color tungsten film. The external surface morphology of all specimens was evaluated.

Conclusions

The evaluation of the morphological attributes of all specimens enables comparison between elements in these investigations and also allows for comparison with accepted patterns of thermal exposure noted in the anthropological literature. The generation of a laboratory sample provides a medium with which to compare the experimentally burned bone. The two fire model experiments generated data to assess variables affecting subsurface heat alteration. The morphological attributes of buried faunal material were evaluated based on the duration of heat exposure and the intensity or degree of exposure. Second, these attributes were analyzed with respect to traits generated by the present laboratory experimentation in addition to laboratory and replicative experiments discussed earlier. The preparation of samples and the design of each experimental model were selected to best replicate the various situations in which post-depositional and post-burial alteration may occur. The models replicate differing

firing situations with respect to duration and intensity. The analytical methods present a systematic procedure for unbiased evaluation of samples.

Chapter IV

Results

The data represent the results of three experiments; archaeological fire model, forensic fire model and laboratory investigation. Temperatures attained during each investigation will be presented in addition to the macroscopic and microscopic appearance of specimens. The results of each experiment will be presented separately.

Laboratory Comparative Sample

The results of the electric kiln experiment can be seen in Table 6.

Color

Heated bones exhibit both primary and secondary colors with the exception of the Archaic specimens. The Archaic bone fragment heated to 220° C does not demonstrate any change in surface color. Secondary colors are mottled with dominant colors on the superior (external) surfa\ces. The inferior surfaces and cut margins display secondary colors. Modern weathered segments are pictured in Plate 2. See Plate 3 for Archaic specimens.

Table 6: Surface colors (munsell) identified on specimens heated in kiln for 48 hours.

Temperature (°C)	Specimens: Modern dominant	Modern secondary	Archaic dominant	Archaic secondary
20	10YR7,8/3 very pale brown		2.5Y 8/4,10YR 7/3 pale yellow,very pale brown	
220	10YR 6/8 brown yellow	7.5YR 5/8 strong brown	2.5Y 8/4, 10YR 7/3 pale yellow, very pale brown	
330	5 YR 2/1 black	5YR 2/2 dark red brown	10YR 6/4 light yellow brown	
410	7.5YR7/2 pinkish gray	7.5YR N2 black	10 YR 7/2 light gray	
520	5 YR 6/1 gray	5 YR 6/2 pinkish gray	10 YR 6/3 pale brown	
630	5 YR 8/2 pinkish white	5 YR 7/4 pink	7.5YR6.5/2 pinkish gray	5 YR 7/4 pink
710	5 YR 8/2 pinkish white	5 YR 7/4 pink	10YR 5/1 gray	5 YR 7/4 pink

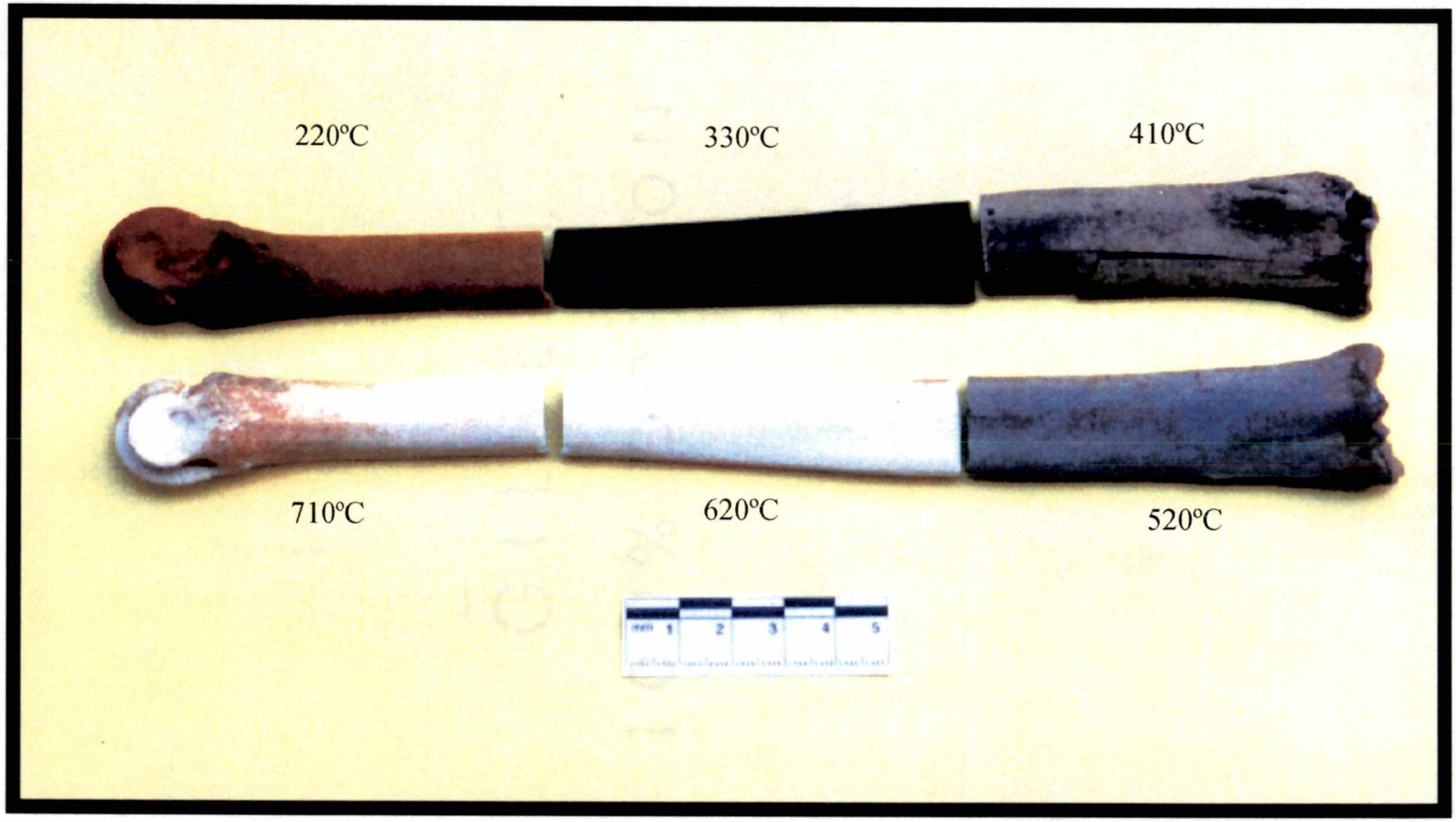


Plate 2: Modern Weathered Segments Heated in Electric Kiln.

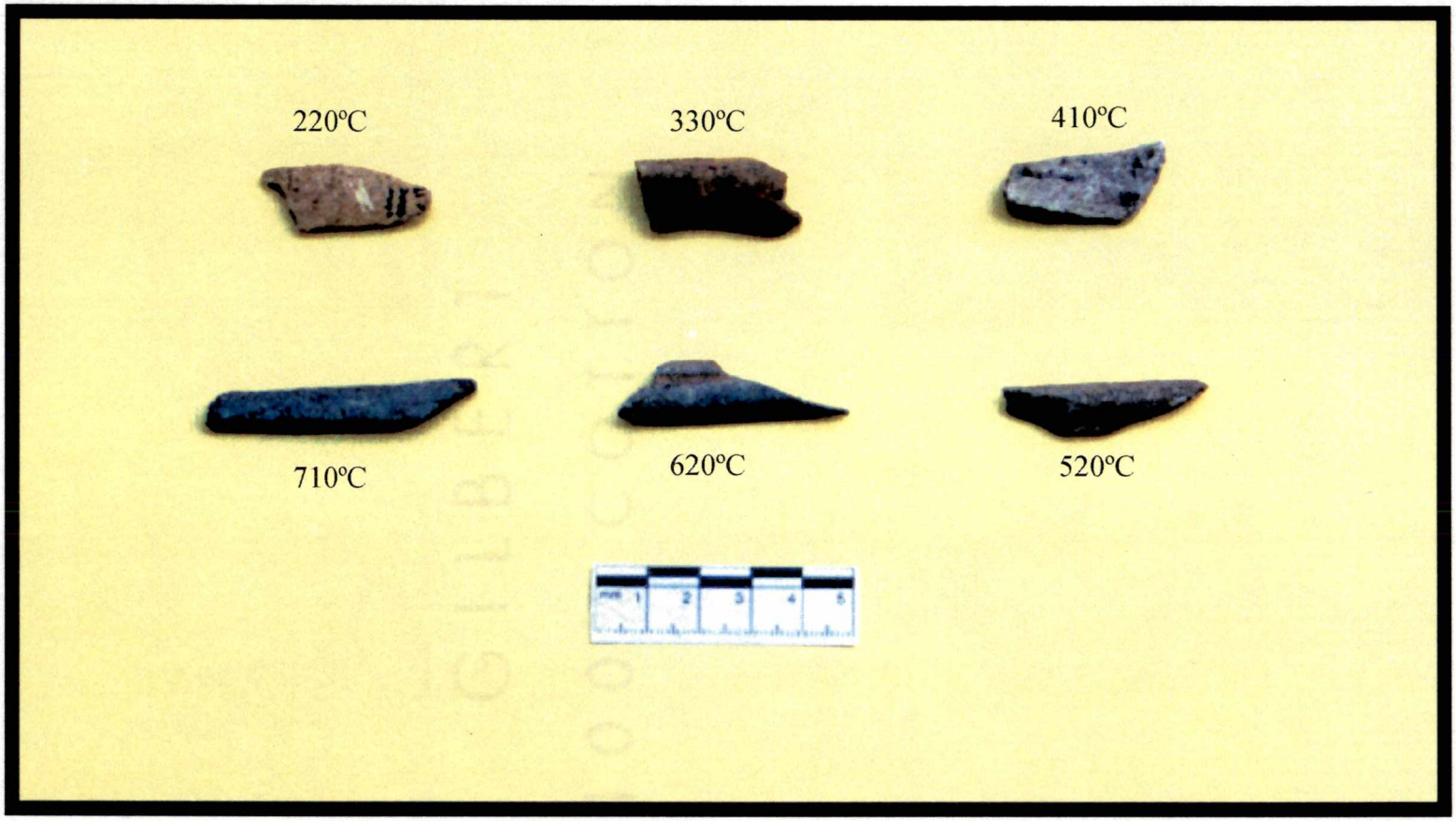


Plate 3: Archaic Specimens Heated in Electric Kiln.

Fractures

Archaic specimens do not exhibit macroscopic morphological distortion. This may be due to the size of these archaeological fragments. The distal modern specimen heated to 710°C displays patina like cracking on the articular surface. The adjacent middle segment (heated to 620°C) exhibits minor longitudinal fractures and a single transverse fracture. A proximal segment of this metapodial was heated to 520°C and displays several longitudinal and transverse fractures. A longitudinal fracture and associated transverse fracture is visible on the proximal segment heated to 410°C. The middle segment heated to 330°C displays a longitudinal fracture extending from the proximal margin. No distortion is apparent on the distal segment heated to 220°C.

Stereomicroscopy

All Archaic specimens display a granular, slightly pitted surface (see Table 7).

Archaeological Fire Model

The ash layer was measured and change in sediment color was noted during excavation of the units. When black sediment was present, it encircled the bones. A total of thirty-two specimens, 12 modern weathered and 12 Archaic, were analyzed following recovery (see Table 8).

Table 7: Microscopic appearance of specimens heated at 70x magnification.

Temperature (°C)	Specimens	
	Modern	Archaic
0	cortical surface penetrated by vascular canals	granular, exfoliated cortical surface
220	fairly even coloring smooth surface	same as above slight sheen
330	mottled colors, glassy vascular canals evident	no change
410	darkening in vascular canals	no change
520	smooth, porous surface transverse splitting	darkened color
620	slight vascular infilling darkening in vascular canals transverse fracturing	marbled coloring
720	smooth surface longitudinal cracks vascular infilling patina and cracking of articular surfaces	marbled coloring

Table 8: Soil colors (munsell) identified during excavation of Archaeological Fire Model.

Levels	Sediments			
	Sand		Clay	
not heated	2.5Y 8/4	pale yellow	7.5YR5/4	brown
ash layer	5cm		6 cm	
2 cm	5 YR 7/4	pink	2.5 YR 5/6	red
	7.5 YR N2	black	7.5 YR N2	black
			2.5 YR 2/2	very dusky red
			7.5 YR 7/8	red yellow
5 cm	7.5 YR N2	black	7.5 YR N2	black
	5 YR 7/4	pink	7.5 YR 3/2	dark brown
	2.5Y 8/4	pale yellow	7.5 YR 5/4	brown
10 cm	7.5 YR N2	black	7.5 YR 3/2	dark brown
	2.5Y 8/4	pale yellow	7.5YR5/4	brown
15 cm	2.5Y 8/4	pale yellow	7.5YR5/4	brown

Six unheated weathered bone segments and two unheated Archaic segments were similarly studied to facilitate recognition of features associated with post-burial burning. Prior to that discussion, it is important to review the temperatures recorded during the experiment.

Temperature

Figure 5 illustrates the temperatures recorded for all subsurface levels during the fire. These temperatures recorded are listed in the Appendix. At hour 24 the temperature of the fires were approximately 700°-750° C.

Table 9: Initial subsurface temperatures recorded in Archaeological Fire Model. Temperatures are reported in Celsius.

	Sand Unit	Clay Unit
Depths		
5 cm	15.1	17.0
15 cm	14.7	14.9
25 cm	14.3	14.4

Little variation between units is apparent in pre-incineration temperatures, though variability between sediments and depths is recognizable after a single hour of heating. Throughout the duration of the experiment, temperatures and the rate of heating vary between units. Maximum temperatures attained at each level in both the

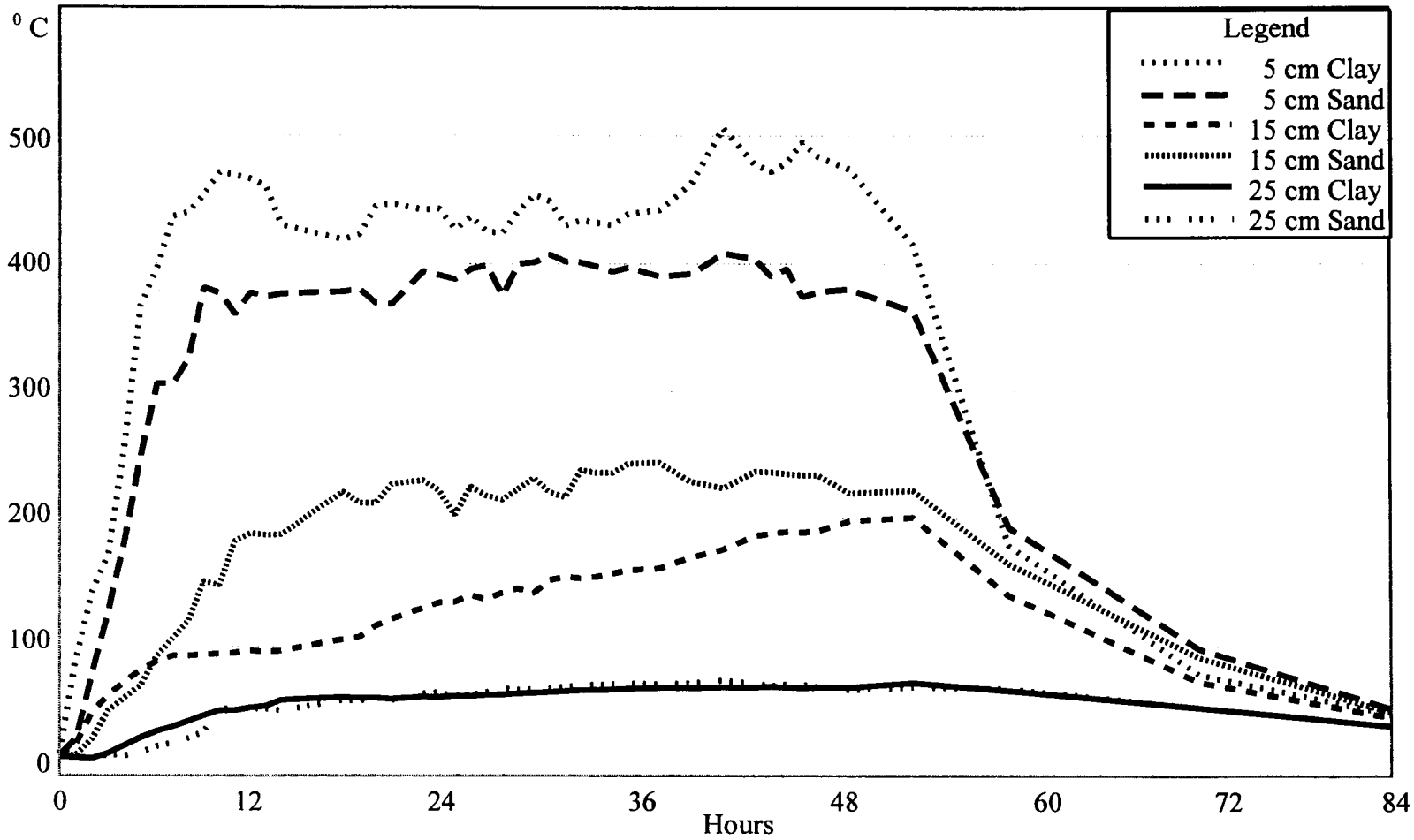


Figure 5: Temperatures Recorded During Archaeological Fire Model

sand filled and clay filled units are presented in Table 10.

Table 10: Maximum subsurface temperatures attained in Archaeological Fire Model. Temperatures are reported in Celsius.

	Sand Unit	Clay Unit
Depths		
5 cm	408.0	506.0
15 cm	237.0	201.0
25 cm	73.9	72.1

The highest subsurface temperature was reached in the clay deposit at a depth of 5 cm; approximately 100° higher than the maximum temperature reached in the sand filled unit. At the 15 cm depth, the sand deposit recorded a higher temperature than the clay deposit. Little variation between sedimentary deposits exists at the 25 cm depths. These maximum temperatures demonstrate the radiation of heat through the sedimentary deposits. Given the disparity in temperatures, it is clear that the thermal conductivity of clay and sand are different.

Maximum temperatures recorded in each level were not reached at the same time. Table 11 presents the hour at which maximum temperatures were attained. Three of the maximum temperatures were recorded at 42 hours of heating. Maximum temperatures were reached in two of the levels after the cessation of heating; 54 hours after ignition of the fires. A review of Figure 5 indicates that the temperatures in all

Table 11: Hour at which maximum subsurface temperatures were attained in Archaeological Fire Model. Hours increase from initiation of the fire at hour 0.

	Sand Unit	Clay Unit
Depths		
5 cm	42	42
15 cm	44	54
25 cm	42	54

levels reflect periods of heating, temperature maintenance and cool down. Parallel heating is apparent. However, the lowest levels in both units reflect increasing temperatures throughout the duration of the experiment.

Temperatures demonstrate a steady increase during the first ten to twelve hours. At hour 11 a slight decrease occurred at the 5 cm depths. Mean temperatures were calculated for each depth from hour 1 to hour 10 (see Table 12). These values reflect the heating period. Mean temperatures were calculated for each level from hour 11 to hour 48, to reflect the period of temperature maintenance (see Table 13).

The temperatures at hour 10 were 377° C and 471° C for sand and clay, respectively. This discrepancy indicates that the clay filled unit heated faster than the sand filled unit. After ten hours of heating the temperatures are 147.8° C and 94.4° C for sand and clay, respectively, which clearly indicates that the sand filled unit heated faster than the clay filled unit at this depth. Twenty-five centimeters below the surface the

Table 12: Hour 1 to Hour 10 mean subsurface temperatures attained in Archaeological Fire Model. Temperatures are reported in degrees Celsius.

	Sand Unit	Clay Unit
Depths		
5 cm	236.2	323.0
15 cm	84.3	75.2
25 cm	24.0	30.8

clay sediment heats faster than the sand. However, by hour 10 there is no variation in heat transmission between sediments.

Table 13: Hour 11 to Hour 48 mean subsurface temperatures attained in Archaeological Fire Model. Temperatures are reported in degrees Celsius.

	Sand Unit	Clay Unit
Depths		
5 cm	388.6	449.5
15 cm	221.5	144.1
25 cm	64.9	63.3

Table 13 reflects the mean temperatures at each depth during the period of heat maintenance; hour 11 to hour 48. Five centimeters below the surface the clay-filled unit reflects a higher average temperature than the sand filled unit. The reverse is true at 15

cm below surface. Throughout this period, little variation is witnessed between sediments in the lowest level.

Color

The twenty-four specimens utilized in this model were categorized based on appearance (see Table 14). All bones from depths of 25 cm, 20 cm and 15 cm below surface appeared unburnt. Archaic specimens from 10 cm exhibit no external characteristics of heat exposure though modern weathered segments from this depth demonstrate alteration. All bones from depths of 5 cm and 2 cm exhibit change in color suggestive of calcination. There are no secondary colors evident on any superior surfaces of specimens. Color is consistent across all surfaces of the bone segment, although the modern weathered segment from the 5 cm depth in the sand filled unit appears slightly darker on the inferior surface. Generally, the inferior surface of each bone (located away from the flame) displays the same color as the superior surface.

All bone, buried at depths below 15 cm does not demonstrate any recognizable variation in surface appearance. At the time of excavation, minimal soil staining was apparent on modern weathered segments collected from depths of 15 cm 20 cm and 25 cm in the clay filled unit. Modern weathered samples from 10 cm depths indicate change in color (see Plate 4). The Archaic bone specimens demonstrate minor variation though it is questionable whether this is attributable to heat (see Plate 5). Modern and

Table 14: Colors identified on specimens in Archaeological Fire Model.

Burial Levels	Specimens: Sand Unit Modern	Sand Unit Archaic	Clay Unit Modern	Clay Unit Archaic
unaltered	2.5Y 8/2,4 white, pale yellow	2.5Y 8/4, 10YR 7/3 pale yellow, very pale br6wn		
2 cm	5YR 6/1 gray	10YR 6/1 gray	2.5YR N5 gray	10YR 6/2 light brown gray
5 cm	7.5YR 7/2 pinkish gray 7.5YR 5/2 brown	10YR 4/1 dark gray	5YR 5/1,2 gray/red gray	5YR 5/1,2 gray/red gray
10 cm	5 YR 2/1 black	10YR 5/3 brown	7.5YR 4/4 dark brown	10YR 6/4 light yellow brown
15 cm	2.5Y 8/4 pale yellow	2.5Y 8/4 pale yellow	10YR 8/4 very pale brown	10YR 8/4 very pale brown

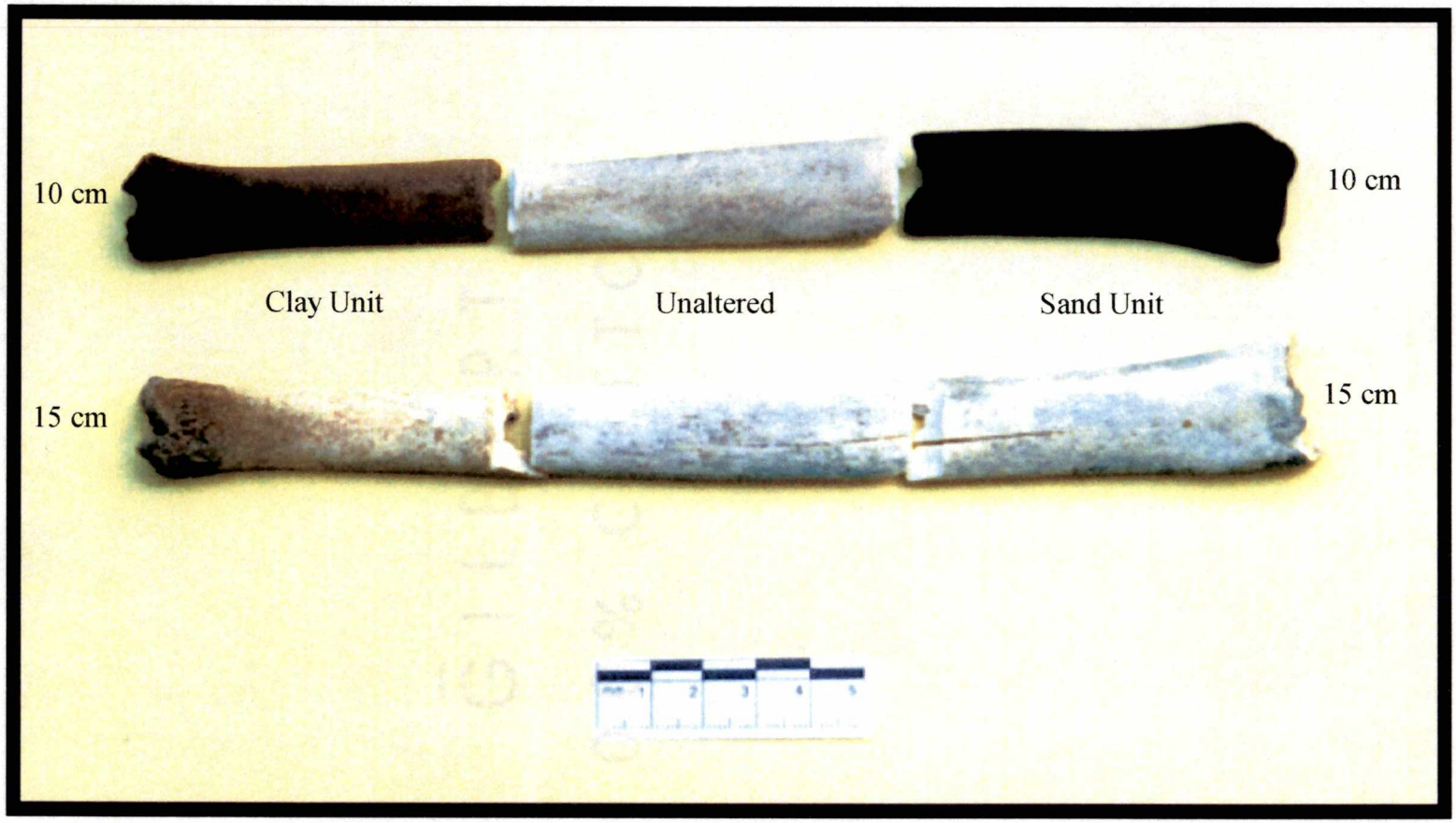


Plate 4: Modern Weathered Segments from fepths of 10 cm and 15 cm in Archaeological Fire Model.



Plate 5: Archaic Specimens from depths of 10 cm and 15cm in Archaeological Fire Model.

Archaic specimens recovered from 2 cm and 5 cm below the surface demonstrate substantial color change (see Plates 6 and 7, respectively).

Fractures

Fractures exhibited on bone recovered in the archaeological model are listed in Table 15. No macroscopic deformation resulting from heat is apparent on the Archaic specimens. Unaltered Archaic specimens do exhibit slight splitting. Modern weathered elements recovered from 15 cm, 20 cm and 25 cm did not demonstrate distortion. Two types of fractures are visible on segments: elements buried at 2 cm, 5 cm and 10 cm in the sand-filled unit demonstrate longitudinal splitting originating at the medial margin and ending at the diaphyseal margin. This may be associated with preparation of the segments. Bone segments excavated from 2 cm and 5 cm in the clay filled unit display longitudinal splitting and transverse fracturing in the region of the diaphyseal margin (see Plate 6).

Warping

Trace warping was recognized on three recovered elements. Segments recovered from the upper three levels in the sand filled unit display evidence of element distortion. Expansion and deformation of segments occurs along the longitudinal

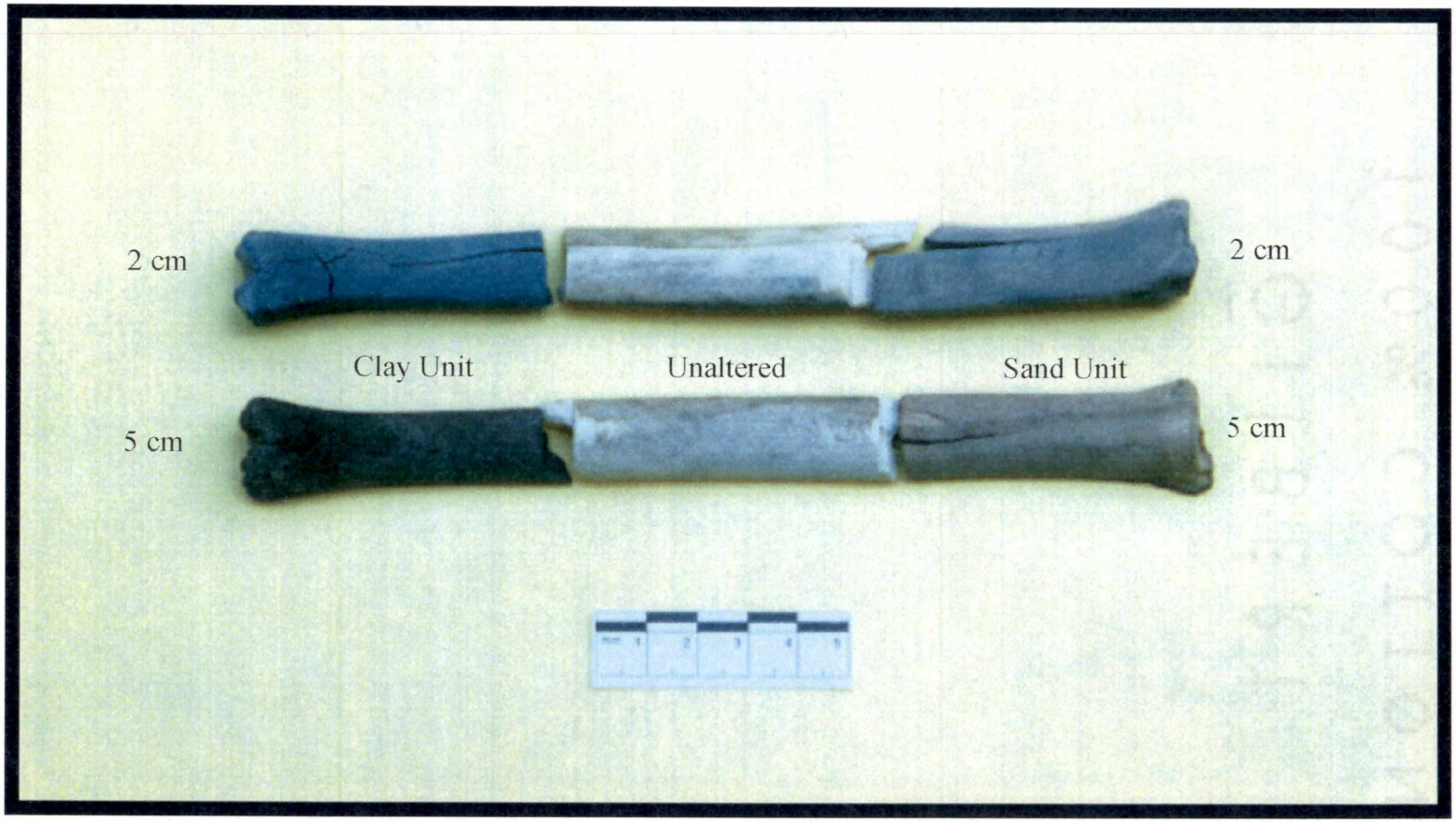


Plate 6: Modern Weathered Segments from depths of 2 cm and 5 cm in Archaeological Fire Model.

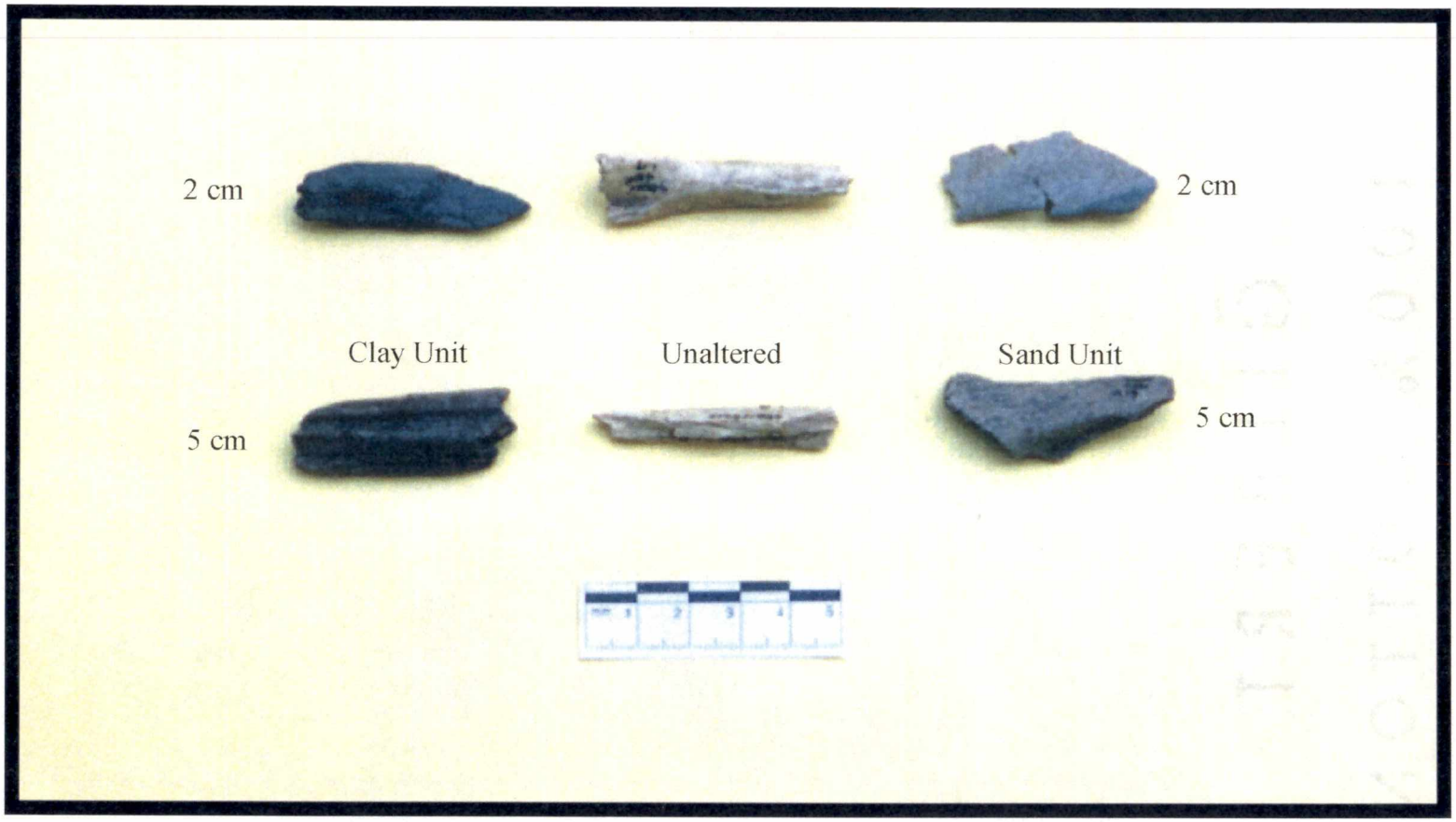


Plate 7: Archaic Specimens from depths of 2 cm and 5 cm in Archaeological Fire Model.

Table 15: Fractures recognized on specimens in Archaeological Fire Model.

Burial Levels	Specimens: Sand Unit Modern	Sand Unit Archaic	Clay Unit Modern	Clay Unit Archaic
2 cm	longitudinal	absent	longitudinal transverse	absent
5 cm	longitudinal	absent	longitudinal transverse	absent
10 cm	longitudinal	absent	absent	absent
15 cm	absent	absent	absent	absent
20 cm	absent	absent	absent	absent
25 cm	absent	absent	absent	absent

fractures attributable to weathering. Warping is localized at the medial aspect of the segments. The degree of distortion is moderate on the modern segment buried at 2 cm and moderate to minor on the segment from the 5 cm level (see Plate 6). The bone segment from 10 cm in the sand filled unit displays minor warping (see Plate 4). No other segments in the archaeological fire model display distortion.

Stereomicroscopy

The data presented here are the results of analyzing specimens at 70x. At this magnification, structural variability was noted in specimens from 2 cm and 5 cm burial levels (see Table 16 for modern weathered segments and 17 for Archaic specimens).

Table16: Microscopic appearance of modern weathered specimens in Archaeological Fire Model at 70x magnification.

Burial Levels	Specimens	
	Sand Unit	Clay Unit
unaltered		even canals longitudinal cracks
2 cm	slightly porous surface canals visible transverse cracks	granular surface canals visible transverse cracks
5 cm	peeling surface	peeling surface canals visible
10 cm	even surface continuous coloring	even surface intact cortical layer

Table17: Microscopic appearance of Archaic specimens in Archaeological Fire Model at 70x magnification.

Burial Levels	Sand Unit	Clay Unit
unaltered		uneven surface splitting, cracks
2 cm	granular surface marbled coloring	granular surface marbled coloring
5 cm	porous surface	porous surface
10 cm	same as unaltered	same as unaltered

Forensic Fire Model

Building refuse consisting of metal, glass and exhaust tubing were removed from the ash surface prior to excavation. The incineration and subsequent collapse of the bathroom floor caused the bathtub to slide which may have partially insulated regions of the crawl space floor. Metal fragments and ash approximately 10 cm in depth were removed to expose the Orton pyrometric cones and the segments originally placed on the surface of the crawl space. No variation in sediment color (7.5 YR 6/6 reddish yellow; prior to heating) was noted. A total of six elements were recovered and subjected to macroscopic and microscopic analyses. Control segments were similarly

analyzed to investigate the morphology exclusively related to a high intensity short duration heating episode. Approximate temperature ranges will be presented prior to discussion of the results.

Temperature

The building burned for 2 hours 37 minutes, at which time no structural material remained intact. The remains continued to smolder for several hours. Twenty-four hours after ignition, heat was no longer emitted (Dalton, 1995). The temperatures reported in the forensic model reflect an approximate maximum temperature attained on the surface of the crawl space (0 cm), 2 cm and 5 cm below the surface. This technique did not permit recognition of any temperature differences between unit A and unit B. Additional temperatures reported are computer generated, based upon the size of the building, and reflect the burning rate and temperature of the structure.

Table 18: Approximate maximum temperatures attained in Forensic Fire Model. Temperatures are reported in degrees Celsius.

		Approximate Temperature or Range
Location		
	Crawl space	950-970
	2 cm	up to 700
	5 cm	less than 600

Color

All specimens used in the forensic model display thermal alteration (see Plate 8). Specimens recovered from 5 cm and 2 cm are smoked and blackened, respectively. Bone specimens from the surface are incinerated or calcined (see Plate 8). Bone specimens appear mottled with primary and secondary colors evident across all surfaces. Color is inconsistent across the surfaces of all specimens. Inferior surfaces display lighter colors than superior surfaces. Superior surfaces display dominant and secondary colors (see Table 19).

Table 19: Colors identified on specimens in Forensic Fire Model.

Levels	Specimens Unit A		Unit B	
unaltered	2.5Y 8/2,4	white, pale yellow		
0 cm	2.5Y N8	white	10YR 8/1	white
	10YR 8/1	white	5 YR 2/1	black
	7.5YR N6	gray	7.5YR 7/4	pink
2 cm	5 YR 2/1	black	7.5 YR N2	black
	5 YR 6/1	gray		
5 cm	10YR 3/2	very dark gray brown	10YR7/4,6	very pale brown/yellow
	10YR 5/b	yellow brown		

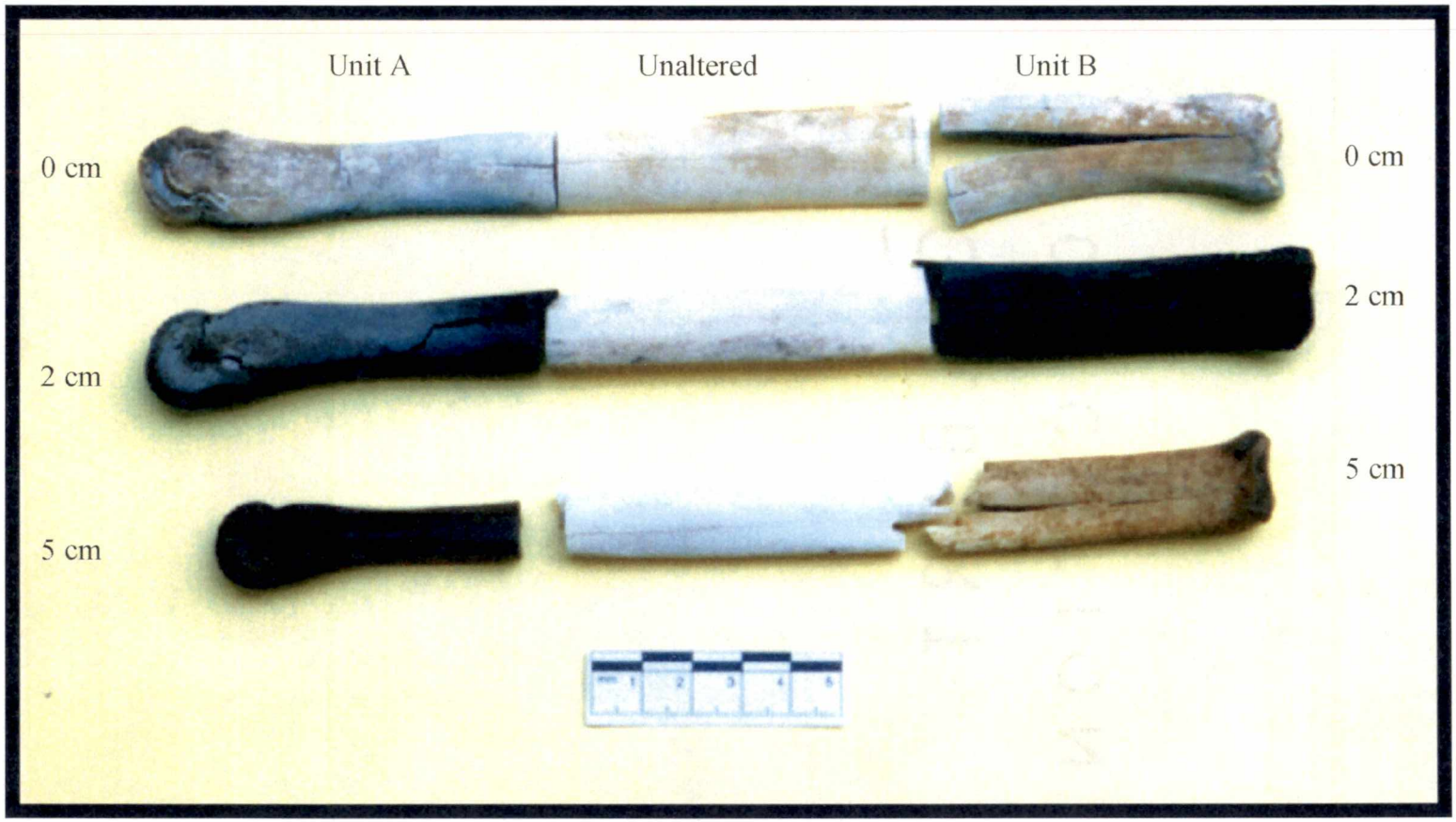


Plate 8: Modern Weathered Segments from depths of 0 cm, 2 cm and 5 cm in Forensic Fire Model.

Fractures

Fractures exhibited on elements recovered in the forensic fire model are more numerous and varied than those seen in the archaeological model. Segments located on the surface and buried at 2 cm display longitudinal and transverse fractures. These fractures encompass the entire length of the segments and involve the epiphyses. The specimen buried at 5 cm in unit B exhibits a longitudinal fracture, while none is evident on the specimen from unit A at 5 cm below the surface.

Warping

Distortion is apparent on elements from the surface and 2 cm depths. Severe warping occurred on the proximal segment on the surface of unit B, though none is visible on the segment from 2 cm below the surface. The segments from unit A at 0 cm and 2 cm depths separated along the anterior posterior margin.

Stereomicroscopy

The following data is based on 70x magnification (see Table 20).

Table 20: Microscopic appearance of specimens in Forensic Fire Model at 70x magnification.

Levels	Specimens	
	Unit A	Unit B
Surface	vascular canals filled porous smooth surface cracks and patina on articular surface	uneven coloring patina on articular surface
2 cm	slightly porous surface	porous surface
5 cm	uneven coloring glassy surface	even surface

Chapter V

Discussion

The results indicate that bone located in a subsurface matrix can be affected by a subaerial fire. The fire models employed in this project suggest that several variables interact to alter buried bone. Pre-incineration condition, intensity of heating, duration of exposure and the sediment in which elements are deposited clearly influence the extent of thermal alteration. The design of the fire models illustrate the affects of these variables. The archaeological fire model is a low intensity burning experiment of long duration whereas the forensic model is a high intensity heating situation of short duration.

Kiln-heated modern bone exhibit surface colors consistent with those recognized by previous researchers (i.e., McCutcheon 1992; Nicholson 1993; Shipman et al. 1984). These modern weathered segments display predominantly continuous color across all surfaces due to the even distribution of heat in the electric kiln. However, the appearance of Archaic specimens do not conform to the characteristic colors published in the literature. Generally, these specimens appear muted in color with an absence of heat related fractures. Black colors are not visible on any Archaic specimens though several specimens were clearly exposed to temperatures in excess of

500^0 C. Microscopically, the Archaic specimens heated to 630 ^{0} C and 710 ^{0} C display a marbled appearance. The secondary colors may be the result of the thermal reaction of soil adhering to the bone cortex. Even though Buikstra and Swegle concluded that "dry bone lacks sufficient organic substance to become uniformly smoked" (1989:252), the change in color of the Archaic specimens seen here indicates the presence of organic material.. A loss on ignition examination would indicate the level of organic material present in these specimens.

Color

Color change is considered an indicator of heat alteration and is readily apparent on bone recovered during these experiments. Modern weathered bone utilized in this investigation demonstrate a range of colors associated with exposure to heat. Bone segments heated in the kiln display even colors across superior surfaces. This is due to the even distribution of heat throughout the internal chamber of the kiln. Similarly, modern weathered segments burned in the archaeological fire model display continuous color across all surfaces. Archaic specimens burned in the archaeological fire model demonstrate change in surface color similar to that seen on kiln heated bone. Elements from the forensic fire model, however, possess dominant and secondary colors.

Specimens buried at 5 cm depths in the archaeological fire model provide the most useful data with which to discuss the parameters surrounding subsurface thermal alteration, as temperatures are known at this depth throughout the duration of the

archaeological fire model. The colors seen on these bones are commonly associated with higher temperatures than those recorded during this experiment. This conclusion is based upon the average temperatures recorded during the period of fire maintenance (hour 11 to hour 48; see Table 13).

Temperatures did not exceed 500° C a depth of 5cm in the archaeological fire model, however, segments from the upper two levels (2 cm and 5 cm) are gray in color. Given that the specimen recovered from 10 cm in the sand filled unit exhibits qualities of near complete combustion of the organic component (blackened), it follows that segments from 2 cm and 5 cm depths were calcining. De Graaff, (1961) noted bone recovered from depths of 0-2 inches did not appear to be dramatically altered. Given the duration of his fire, bone in this stratum should demonstrate substantial heat alteration. The light color he recognized may be similar to the muted colors witnessed here on the modern weathered segments from 5 cm levels. Stiner and coworkers (1995), however, claim no calcination occurred on elements situated at a depth of 1 cm below surface. Furthermore, less than half of the bones buried at 10 cm display any marked change reflective of burning (Stiner et al. 1995). The disparity between these findings and those of the archaeological fire model demonstrate the effects of duration of heating upon bone situated below a fire. In the experiments conducted by Stiner and coworkers (1995), fires used only 6 kilograms of hardwood and were allowed to burn unattended. The campfires in the present study were maintained through the continuous addition of fuel, resulting in a heating situation of longer duration than that replicated by

Stiner and coworkers. This trend, considered with the findings of De Graaf (1961) and Stiner et al. (1995), suggests that duration of heating may greatly impact the appearance of heat altered bone.

Modern weathered segments from the forensic fire model differ in appearance from those discussed above. The forensic fire model, however, does not provide the level of information obtained from the archaeological fire model due to an inability to record temperatures throughout the burning of the structure. Nevertheless, there are important results: primary and secondary colors are visible on these bone segments, especially on the specimens from the crawl space surface which were directly exposed to the fire (see Plate 8). In addition, the apparent variation between units A and B demonstrate that variable heating can occur in a limited space. The existence of primary and secondary colors on these segments may be due, in part, to the dramatic rise in temperatures recorded in this experimental model. Further, bone was not evenly heated, as in the kiln and archaeological fire model, given the nature of the fire. Comparison of bone surface colors from both models suggests that intensity of heating and duration of heat exposure affect the extent of thermal alteration.

Fracture and warping

The laboratory sample was compared to the bone burned in the models for evaluating the effects of subsurface heating on fracture and warping. Bone from all

experiments display fracturing and warping which is characteristic of bone burned while dry.

The longitudinal splitting and fractures witnessed on modern weathered samples heated in the archaeological fire model are consistent with the finding of Buikstra and Swegle (1989) who suggest fractures and warping on dry bone are limited in number and degree. There are several factors which may explain the limited modification seen on specimens. They include, the degree of weathering of these specimens (pre-incineration condition), the effects of radiating heat as opposed to direct exposure to fire, and the support provided by the sedimentary deposits. Archaeological specimens are almost entirely devoid of heat-related fractures. This may be due to the negligible size and degree of weathering of these bones samples.

Modern weathered segments heated during the forensic fire model demonstrate a greater degree of modification (more warping and fracturing) than bone heated in the kiln or the archaeological model. This is most likely a by-product of both the fast rate of temperature increase and the high maximum temperature attained in this model compared to the kiln and the archaeological model. These fractures are not indicative of bone burned in a "green" or fleshed state, however, they differ slightly from those on bone heated in the kiln and the archaeological fire model. These findings suggest the method of heating, short heat up time combined with high temperature, affects the appearance of burned bone.

Experiment

To further investigate the role of duration in burning, a small laboratory examination was conducted. Pairs of weathered and Archaic specimens were heated for a period of forty-eight hours. See Table 21.

Table 21: Surface colors identified on laboratory specimens heated in electric kiln for 48 hours.

Temperature (°C)	Specimens		
	Modern	Archaic	
	dominant	dominant	secondary
20	10YR7,8/3 very pale brown	2.5Y 8/4, 10YR 7/3 pale yellow, very pale brown	
130	10YR 6/8 brown yellow	2.5Y 8/4, 10YR 7/3 pale yellow, very pale brown	
240	10YR 3/2 very dark gray brown	10YR 5/1 gray	5 YR 7/4 pink
390	5 YR 6,7/1 gray Light gray	10 YR 5/1 gray	5 YR 7/4 pink

The appearance of modern weathered segments and Archaic specimens indicates that duration of heating affects the degree of alteration. (see Plates 9 and 10, respectively). These colors suggest that heat-related alteration is strongly related to duration of exposure. The surface colors noted in Table 21 are associated with higher

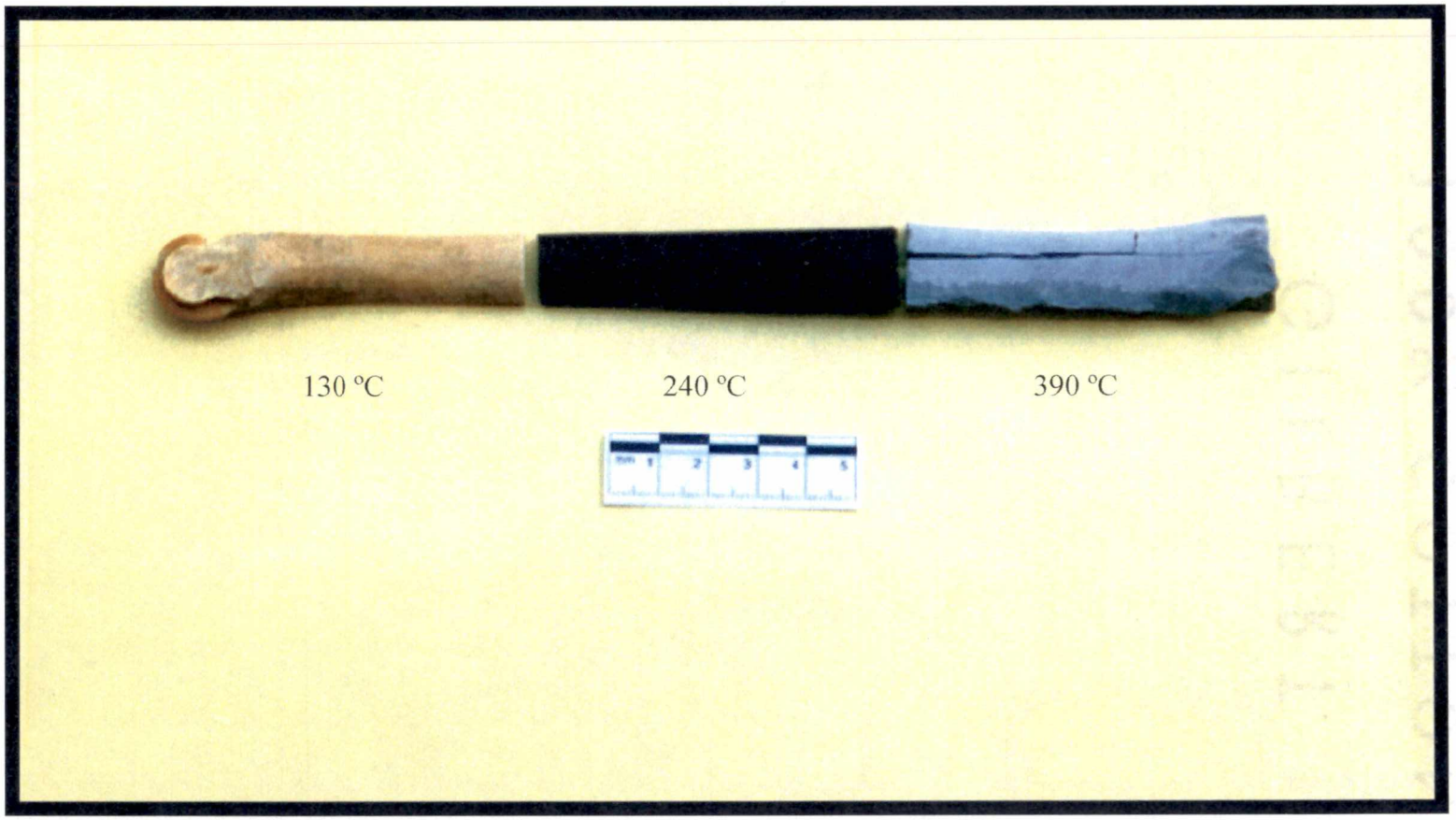


Plate 9: Modern Weathered Segments heated in Electric Kiln for 48 hours.



Plate 10: Archaic Segments heated in Electric Kiln for 48 hours.

temperatures (see Tables 1, 2 and 4). This finding suggests that the correlation between maximum temperature and macroscopic appearance may not be as strong as previously considered. This may also have applications in the discussion of diagenesis and low temperature heating, as the color recorded on the bone heated to 130 ^{0}C may not be recognized as a product of heat exposure. Clearly intensity of heating and duration of heat exposure affect the extent of thermal alteration.

The microscopic analysis conducted during this research does not provide criteria to assess the process by which bone was burned. Surface variation is apparent on modern weathered segments from the upper levels of the archaeological model. Similar modification was recognized on kiln-heated specimens. It is believed that a scanning electron microscopic investigation of experimentally burned bone may establish criteria to better assess the degree of heating and the situation in which it occurred.

Temperature information is important not only to assess the degree of alteration, but to address the thermal conductivity of sediments. The temperatures recorded in the archaeological fire model indicate that the diffusion of heat occurs at different rates and patterns between the units. The clayey silt filled unit heated up faster than the unit filled with fine grain sand. The maximum temperature reached in the sand filled unit was lower than that achieved in the other unit. This is attributable, in part, to the texture of the sediment which influences the amount of air and water in the deposit (Manual for Judging Oregon Soils 1984). Subsequently, this (particle size) would affect the

radiation of heat through the subsurface matrix. This may also serve to partially explain the differential heating seen in the forensic fire model as the hard clay deposit contained coarse limestone particles through which heat may have been unevenly transmitted.

Accurate assessment of the appearance of bone is an important part of analysis, but an understanding of the context from which artifacts come is crucial. It is unclear whether the sedimentary changes noted during excavation of the models would survive into the archaeological record; whether these subsurface deposits would be visible. These points necessitate further research, however, in the interim, analysis incorporating techniques such as micromorphology may eliminate some of the ambiguity surrounding these issues.

The study of artifact assemblages involves investigations of the processes by which artifacts are accumulated and subsequently modified (Marshall 1989). Accurate interpretations of burned bone assemblages are of importance in zooarchaeological, forensic and paleoanthropological investigations (e.g., paleodietary reconstruction, mortuary behavior and early manipulation of fire). At the most basic level, anthropologists must consider the temporal association between burning, deposition and burial. Understanding the processes by which burned bone assemblages are formed and altered are crucial to anthropological examinations. This research demonstrates that bone situated in a subsurface matrix can be thermally altered initially following or long after deposition. This must be considered during analysis of burned bone.

Though these examinations have addressed some research questions, such as the roles of duration and intensity of heating, they have generated several points that warrant further discussion and research. The results of this investigation indicate that artifacts must be analyzed with respect to the deposits in which they are identified. Although this research suggests that certain morphological qualities may characterize bone burned in a subsurface deposit, these traits cannot be considered solely reflective of post-burial burning. Hence, thorough, contextual investigations incorporating sedimentary analysis may provide a more holistic view of the in-situ processes that affected bone. As suggested by Stein (1996), the properties of the assemblage of objects, both cultural and natural must be considered. Although replicative experimentation is crucial for the generation of data to apply in archaeological analysis, movement beyond mere recognition of artifactual attributes may provide more accurate inferences of post-depositional and post-burial processes.

Chapter VI

Conclusions

With respect to the goals of this project, the results can be summarized as follows:

1. **Bone can be burned in a subsurface, i.e. post-burial context.**

Modern weathered bone can be burned through indirect exposure to heat (fire). Both experimental models indicate that buried bone can be significantly burned by the effects of a surface fire. In the archaeological fire model, modern weathered segments located 10 cm below the surface are blackened. The traditional assumption that bone is burned through direct exposure to flame should no longer be unquestionably applied in archaeological and forensic analyses.

2. **Bone dated to 5000 years BP can be burned.**

Bone located in a subsurface deposit dated to 5000 years BP can be altered through the effects of a present day surface fire. This must be considered during excavation and subsequent examination of materials.

3. **Bone burned in a subsurface context (indirect exposure) may differ slightly from bone burned in a surface (direct) context.**

The morphological characteristics witnessed on bone in these experiments are associated with bone burned in a dry state. Analysis of surface color on specimens heated through the radiating effects of a campfire indicates these elements demonstrate continuous color across all surfaces. Bone specimens recovered from the forensic fire model do not possess this evenly distributed color. The buried specimens display

more continuous coloring than the bone located on the surface of the crawl space.

4. Duration of heating and intensity of exposure affect the degree of burning.

Weathered segments heated for 48 hours in the archaeological fire model are blackened at depths of 10 cm. Bone burned in the forensic fire model (reduction of the structure took less than 3 hours) is blackened only at a depth of 2 cm, although maximum temperatures were greater than in the archaeological fire model. De Graaff (1961) recovered charred bone at depths of 8 in following seven weeks of exposure to a primitive campfire. Thermal alteration was noted at a depth of 12 in. Stiner et al. (1995) claims that of bone located at a depth of 10 cm, less than half demonstrated any degree of alteration. The final kiln experiment conducted here clearly illustrates the strong influence that duration of heating has upon the level of alteration.

5. Transfer of heat occurs at different rates and patterns between sediments.

The particle size of sediments influences the radiation of heat through subsurface deposits. Recorded subsurface temperatures demonstrate that the clay filled unit heated up faster than sand filled unit; however, throughout the duration of the experiment, heat radiated more evenly through the sand deposit.

Recognizing that surface color is not traditionally accepted as a sole indicator of temperature, these conclusions are not intended as analytical guidelines. Instead, they are set forth for consideration of the potentiality of post-burial burning. In conjunction with the negligible fracturing and warping witnessed on specimens herein, it appears that recognition of bone burned in an exceptionally dry state may be possible. It is unclear, however, whether it is possible to determine if bone was burned while located

in a subsurface deposit. Analysis of the context in which burned bone is identified may make such conclusions possible.

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Appendix

Temperatures Recorded in the Archaeological Fire Model

	Sand Unit	Clay Unit
Hour 1		
5 cm	28.3	90.0
15 cm	15.7	23.7
25 cm	14.3	13.6
Hour 2		
5 cm	79.0	142.7
15 cm	28.0	48.8
25 cm	13.3	13.3
Hour 3		
5 cm	128	172.1
15 cm	50.3	62.2
25 cm	15.8	17
Hour 4		
5 cm	183	259
15 cm	60.5	72.6
25 cm	15.1	23.3
Hour 5		
5 cm	249	367
15 cm	69.8	81.5
25 cm	17.9	29.4
Hour 6		
5 cm	306	397
15 cm	93	89
25 cm	22.7	34.5
Hour 7		
5 cm	306	437
15 cm	106.8	93
25 cm	25.4	38
Hour 8		
5 cm	325	440
25 cm	120	93
15 cm	28.8	42

	Sand Unit	Clay Unit
Hour 9		
5 cm	381	454
15 cm	151.2	93.7
25 cm	33.8	46.7
Hour 10		
5 cm	377	471
15 cm	147.8	94.4
25 cm	52.5	50.3
Hour 11		
5 cm	360	469
15 cm	182.5	95.2
25 cm	50.9	50.3
Hour 12		
5 cm	377	466
15 cm	188.2	97
25 cm	51.6	52.5
Hour 13		
5 cm	374	460
15 cm	187	96
25 cm	51.8	54
Hour 14		
5 cm	376	430
15 cm	187.7	96.8
25 cm	50.5	58.5
Hour 15		
5 cm		
15 cm		
25 cm		
Hour 16		
5 cm		
15 cm		
25 cm		
Hour 17		
5 cm		
15 cm		
25 cm		

	Sand Unit	Clay Unit
Hour 18		
5 cm	378	419
15 cm	221	105.6
25 cm	58.1	60.6
Hour 19		
5 cm	380	423
15 cm	212	107.1
25 cm	57.5	59.8
Hour 20		
5 cm	369	445
15 cm	212	116
25 cm	61.3	60
Hour 21		
5 cm	368	447
15 cm	227	121.5
25 cm	58.2	59.3
Hour 22		
5 cm		
15 cm		
25 cm		
Hour 23		
5 cm	394	442
15 cm	230	130.2
25 cm	63.4	60.9
Hour 24		
5 cm	391	443
15 cm	222	134.3
25 cm	64.5	60.8
Hour 25		
5 cm	388	427
15 cm	203	134.9
25 cm	61.3	61.6
Hour 26		
5 cm	396	437
15 cm	225	140.1
25 cm	62.1	61.7

	Sand Unit	Clay Unit
Hour 27		
5 cm	399	425
15 cm	218	137
25 cm	64.8	62.5
Hour 28		
5 cm	375	424
15 cm	215	142
25 cm	67.8	62.8
Hour 29		
5 cm	400	441
15 cm	223	145.3
25 cm	66.6	63.8
Hour 30		
5 cm	401	454
15 cm	232	142
25 cm	67.3	64
Hour 31		
5 cm	407	449
15 cm	217	152
25 cm	67.7	64.7
Hour 32		
5 cm	402	430
15 cm	217	154.4
25 cm	68.8	65.5
Hour 33		
5 cm	401	434
15 cm	238	153.3
25 cm	70	66.1
Hour 34		
5 cm	398	432
15 cm	236	154.6
25 cm	70.4	66.2
Hour 35		
5 cm	394	430
15 cm	236	157
25 cm	71	66.7

	Sand Unit	Clay Unit
Hour 36		
5 cm	397	439
15 cm	243	159.6
25 cm	71.3	67.6
Hour 37		
5 cm		
15 cm		
25 cm		
Hour 38		
5 cm	390	442
15 cm	244	161
25 cm	71	68
Hour 39		
5 cm		
15 cm		
25 cm		
Hour 40		
5 cm	392	463
15 cm	229	170
25 cm	72	68.1
Hour 41		
5 cm		
15 cm		
25 cm		
Hour 42		
5 cm	408	506
15 cm	224	176
25 cm	73.9	68.5
Hour 43		
5 cm		
15 cm		
25 cm		
Hour 44		
5 cm	404	478
15 cm	237	186.6
25 cm	71.6	68.7

	Clay Unit	Sand Unit
Hour 45		
5 cm	390	472
15 cm	236.4	188.3
25 cm	69.7	69.2
Hour 46		
5 cm	396	479
15 cm	235	189.7
25 cm	70.9	68.7
Hour 47		
5 cm	374	495
15 cm	234	189.2
25 cm	70.7	68.1
Hour 48		
5 cm	378	484
15 cm	234	190.5
25 cm	68.9	68.6
Hour 50		
5 cm	380	474
15 cm	220	198.4
25 cm	66.4	68.6
Hour 54		
5 cm	363	415
15 cm	222	201
25 cm	68.6	72.1
Hour 60		
5 cm	193.2	179
15 cm	164.5	139.9
25 cm	67.6	65.9
Hour 72		
5 cm	98.2	78.4
15 cm	91.5	72.5
25 cm	52.5	52.5
Hour 84		
5 cm	52.2	47.7
15 cm	49.5	45
25 cm	38.3	38.4

Vita

Joanne Lorraine Bennett was born at The University of Chicago Medical Center in the very early hours of July 8, 1968. Ms. Bennett spent her formative years in Westchester County New York, graduating from Pleasantville High School in the spring of 1986. A Bachelor of Arts with honors in Anthropology from Hamilton College followed four years later. In the fall of 1992, after two years in the real world, and too many northern winters, she eagerly entered the graduate program at the University of Tennessee. A period of time later, Joanne completed a Master of Arts degree in Anthropology.