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The effects of two household accelerants on burned bone

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Abstract

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The Effects of Two Household Accelerants on Burned Bones

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The effect of fire on bone is a subject that has not been widely studied in the field of Anthropology. Previous research has indicated few or no definitive conclusions with regard to creating standards, at least macroscopically, that can be used to identify burning and the degree to which a bone has been burned. This research project was undertaken to see if it was possible to identify bones that had been burned in a fire in which an accelerant had been used as opposed to bones burned without the use of an accelerant.

Three fires were used in this research. One fire used no accelerant, one used charcoal lighter fluid and one used gasoline. Fresh bovine bones were placed in each fire and monitored with regard to temperature change, color and warping and breaking. Bones from each fire were then examined using a Scanning electron microscope to detect any changes to the crystalline structure. It was hypothesized that the fires containing an accelerant should burn hotter and therefore have a greater effect both macroscopically and microscopically than the fire that did not contain an accelerant. While there were no obvious macroscopic differences between the bones in each fire, there were distinct differences among the bones microscopically.

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Chapter 1: Introduction

The study of cremated or burned bone is a topic that is relatively new to the field of Physical Anthropology. Only in the last 50 or 60 years have anthropologists begun to recognize the wealth of information contained in burned remains- be they animal bones, human bones or tools. Lithic artifacts are burned just as often, if not more often, than identifiable bones (Stiner *et al.*, 1995: 225). Many prehistoric cultures were known to use heat treatment on raw stone material to enhance its utility. Emil Haury (1945; in Merbs, 1967) noted in his work on the American Southwest "the possibility of retrieving reliable and helpful information from the incinerated bones is extremely slight in proportion to the proof needed." Even today, many aspects of exactly how fire affects bone are unknown.

Cremation studies can generally be divided into four categories: cultural patterning, socio-cultural reconstruction, biological distance, and population studies (Merbs, 1967: 498). Cultural patterning studies are usually limited to the description of burial practices as cultural traits. Socio-cultural reconstruction studies attempt to identify any differential treatment of the dead based on sex, age, or any other identifiable biological attributes. Biological distance studies are the study of the result of microevolution through comparing one cremation to another. Population studies attempt to study a skeletal series in terms of population profiles and total population patterning.

Cremation research can be organized into four separate categories: analysis of visual characteristics, analysis of histological characteristics, demographic analysis, and forensic cases (Mayne Correia, 1997). All except demographic analysis will be under review in this paper with emphasis on forensic application.

One of the main problems with studying cremated remains is that there are not any concrete standards. Many of the quasi-standards that are in place are open to individual interpretation. Studies by Baby (1954), Binford (1963), Herrmann (1977) and Shipman *et al.* (1984) among others have attempted to understand and establish some guidelines for others to follow. Problems that have been encountered in trying to do this research include the use of wide range of techniques, incomparability of skeletal samples and inconsistencies in terminology which can and often do produce incomparable results (Mayne Correia, 1997). Much of the previous work has concentrated on morphological characteristics such as color, warping and breakage and shrinkage. More recently researchers have begun to use more technologically advanced equipment such as the scanning electron microscope (SEM), transmission electron microscope (TEM) and X-ray diffraction analysis to observe the crystalline structure of bone and how heat alters it.

Shipman *et al.* (1984: 308) argue that the maximum temperatures attained by fires are determined by the fuel used and the particular construction of the fire. They also suggest that by the knowing the maximum temperature reached by a skeletal element the mode of heating can be determined.

Nicholson (1993: 427) stated that once burning has been established, it is not necessary to be able to determine the temperature of burning with great accuracy. Previous experiments by Nicholson (1991; cited in Nicholson 1993) have demonstrated that even though temperatures of a small campfire may reach up to 800°C, some bones may be located in areas of the fire not exposed to its maximum temperature.

Different types of fires have been shown to achieve different temperatures. Barbrauskas (1998-2004) explains that the temperature for methane burning in air reaches a temperature of 1949°C and propane reaches 1977°C. He notes that the value for propane is nearly identical to that of wood. Tylecote (1962; cited in Shipman *et al.,* 1984: 308) stated that the temperature of a normal campfire is about 400°C and rarely reaches 700°C. Even different types of wood reach different temperatures. Juniper and oak fires reach a temperature of 680-820°C (Buikstra and Swegle, no date; cited in Shipman *et al.*, 1984: 308), and the coals of an oak fire reach about 900°C. Shepard (1956; cited in Shipman *et al.*, 1984: 308) measured a maximum temperature of 962°C for wood stacked around pottery in the open. Burning piled logs and slash piles can produce even higher temperatures (1430°C) and sustain temperatures in excess of 800°C for 40 minutes or more (Shipman *et al.*, 1984: 308). Prairie fires can reach a maximum of about 700°C, but do not stay that hot for more than a few minutes (Shipman *et al.*, 1984: 308). Modern day domestic house fires can reach temperatures in excess of 1000°C in comparison with a temperature of about 900°C in ancient cremation pyres; suggesting that complete cremation in either of these situations is not uncommon (Shipman *et al.*, 1984: 308).

The rate at which an object heat up in a fire depends on its thermal conductivity, density and size (Barbrauskas, 1998-2004). Essentially, a small, low-density, low-conductivity object will heat up faster than a large, heavy-weight one. Other variables such as the position of the bone within the fire, the maximum temperature attained, how quickly maximum temperature is attained, duration of the fire and the amount of the fat on the bone all influence the ultimate destruction of the bone (Nicholson, 1993: 412). Buikstra and Swegle (no date; cited in Shipman *et al.*, 1984: 308 and Nicholson, 1993: 413) measured bone temperature directly during experimental heating and discovered that neither fleshed nor defleshed remains reach the maximum temperature of the heating device in less than two hours. A constant fire of several hours would be sufficient to destroy bones to an extent that they crumble easily when touched (Westenhoeffer cited in Bohnert *et al.*, 1998: 19).

The temperatures in a modern crematorium range from about 800-900°C to upwards of 1000°C (Bohnert *et al.*, 1998: 13). DiMaio (cited in Bohnert *et al.*, 1998: 20) observed that it takes approximately 1.5 to 2.5 hours to completely cremate a human body in this temperature range. Whether or not the body itself reaches the maximum temperature of the fire will depend on the duration of the fire (Mays, 1998). Another factor in the maximum temperature reached by a body depends on the amount of body fat. A body with a great deal of fat will burn hotter and faster than a thinner one (Mays, 1998).

An important archaeological application of cremation research is being able to diagnose a bone as being burned or not and determine whether a particular bone was burned for the purpose of food. However, bone burning may, though not necessarily must, correspond to the roasting or boiling of flesh (White, 1992). Attempting to detect evidence of this kind of cooking causes problems because when heating food, the objective is to retain moisture, not to boil or burn it all out (Koon *et al.*, 2003: 1393). Detection is therefore difficult because it is unlikely that the bone would reach the initial stage of thermal alteration required to detect such changes (Koon *et al.*, 2003: 1393). Another factor as to why detecting whether a bone was used in food preparation is that the meat of the animal would insulate the bone and prevent it from heating to a detectable temperature (Shipman *et al.*, 1984: 323). Bones heated to a high temperature are likely to have been deliberately cremated or burned as waste, either on purpose or by accident, while bones that have been charred could possibly by the remnants of a meal (Nicholson, 1993: 412).

There is also an interest in identifying cannibalism among burned human remains. From an anthropological point of view, cannibalism essentially means the regular, culturally encouraged consumption of human flesh (White, 2003). There are five types of cannibalism: ritual, survival, endocannibalism, exocannibalism and autocannibalism. Ritual cannibalism occurs when members of a family or community consume their dead according to funerary rites. Survival cannibalism is simply cannibalism that is driven by starvation. Endocannibalism is the consumption of individuals within a group while exocannibalism refers to the consumption of outsiders. Autocannibalism covers a wide range of behaviors from nail biting to torture-induced self-consumption (White, 2003). The ability to properly identify cannibalism would allow anthropologists to reach concrete conclusions regarding this controversial subject rather than making assumptions.

The focus of this study will be to determine if the use of two common household accelerants (gasoline and charcoal lighter fluid) can be detected on burned bone using both macroscopic observations and the scanning electron microscope. Two fires, one using gasoline and one using charcoal lighter fluid, will be compared to a traditional campfire to attempt to determine the differences between them, if possible. The two fires using accelerants should burn hotter and therefore have a greater effect both macroscopically and microscopically than those on the traditional campfire, therefore:

H_O: It is not possible to distinguish bones burned using an accelerant from bones burned without an accelerant.

H_1: It is possible to distinguish whether an accelerant was used in the burning of bone either macroscopically or microscopically.

Chapter 2: Effects of Heat on Animal Bones

Studies of mineralized sheep tendon by Snowden and Weidemann (1976; cited in Koon *et al.*, 2003) and fish bone Richter (1986; cited in Koon *et al.*, 2003) suggest that mild or low temperature heating leads to disorganization of mineralized collagen fibrils that are observable using a transmission electron microscope (TEM) (Koon *et al.*, 2003: 1393). Investigations of the heat-related effects on the organic portion of bone reveal that soft, non-mineralized collagen melts and forms a gelatin when heated to around 60°C, but mineralized collagen fibrils remain intact in this temperature range (Holden *et al.*, 1995b: 31).

Unfortunately, at present, the only possible way to identify bone as being burned is if it is charred (Koon *et al.*, 2003: 1393). One can make inferences about burning if the bone was in some proximity to a hearth or some other area where cooking was common but once again, the answer in not concrete.

Bones buried in sediment can be burned by a surface fire (Stiner *et al.*, 1995). This finding suggests that a surface fire can burn buried bone at a later and totally unrelated date and event. Surface fires permanently affect the magnetic properties of iron-rich sands and clays in the ground as the heat penetrates it, especially within the first 5 cm below the fire (Stiner *et al.*, 1998: 230). The determination of subsurface alteration of a bone is useful but one must keep in mind that different sediments, like the objects themselves, have different thermal conductivity (Bennett, 1999: 7). In an experiment by Bennett (1999: 6), the temperature at 5 cm below the surface did not exceed 500°C. Specimens that were buried at this 5 cm depth were burned to the point of carbonization (Stiner *et al.*, 1998: 230). One must be careful to distinguish between accidental fires and those made and controlled by humans or early hominids in this regard (Shipman *et al.*, 1984: 323).

Although the conditions of heat-treatment in a laboratory are considerably different from a real fire situation, similarities between samples heated in a laboratory and those of a fire victim should be relatively similar if experimental studies are to find any practical application. A study by Holden *et al.* (1995a: 18) found that there was no significant difference in the "naturally" occurring incinerated bone compared with the laboratory heat-treated bone.

Most would agree that it is almost impossible to completely destroy a body. Even severely burned bones can sometimes offer diagnostic characteristics with regard to sex, age, individual specific marks and/or previous injuries (Bohnert *et al.*, 1998: 20). As Baby (1954) noted in his study of Hopewellian cremated remains, despite their incineration, the remains still exhibited pathologies and crippling deformities. In a study by Bohnert *et al.* (1998: 17), anatomically recognizable bone fragments could still be identified even after commercial cremation.

An important factor in identifying cremated remains is the ability to identify the degree of incineration or calcining of the bone with some degree of accuracy. The degree of calcining depends on four basic criteria: the length of time in the fire, intensity of the heat of the fire, the thickness and amount of protecting muscle tissue and the position of the bone in the fire (Binford, 1963: 101). Essentially, the surface or surfaces of the bone that is closest to the fire will be the most calcined (Schwartz, 1993). Herrmann (1977) came up with the "critical value" of 700-800°C that is widely used as the standard for determining whether a bone has reached "complete" cremation.

Another important factor in evaluating cremated remains is understanding the process of how a body burns. There are numerous studies (Baby, 1954, Herrmann, 1977, Mayne Correia, 1997, Shipman *et al.*, 1984, Stiner *et al.*, 1995) detailing the burning of bodies from start to finish in modern crematoriums and experimental fires as well as studies of archaeological cremation sites.

In Baby's study of four Hopewellian cremation sites (1954), he noted the condition of each bone present and which bones were most commonly found. The extent of the damage to the skull is as follows:

> The facial masks (including the mandible), exterior of the vaults (with the exception of the squamous portion of the temporals and the inferior anterior angles of the parietals, which were smoked) were well calcined while the damage to the interiors of the vaults ranged from complete incineration to normal. There was a marked absence of ribs but the ones that were present showed extensive burning on the exterior surface and smoking on the interior surface. Surviving fragments of the upper extremities show complete destruction. Bodies of all cervical, thoracic, and lumbar vertebrae as well as the superior portion of the sacra were normal. The spines and transverse processes of the vertebrae were smoked or well incinerated along with some smoking along the spinous and transverse processes. The blades of the ilia were completely incinerated but the acetabula, ischia, and inferior and superior rami were normal with smoking along the edges.

Although there is really no satisfactory method available to determine the exact temperature reached by prehistoric cremations, the presence of carbon residue indicates that the temperature did not usually exceed 700°C (Grupe and Hummell, 1991: 181).

Bohnert *et al.* (1998) observed the cremation of a body in a modern cremation furnace. The complete process from beginning to end, including cooling, took about three hours. A study by Spitz as noted by Bohnert *et al.* (1998: 20) found that in a gas-fuelled cremation oven it takes at least 1 to 1.5 hours to cremate an average sized adult at a temperature of about 800°C. Von Hofmann and Haberda (noted in Bohnert *et al.*, 1998:

19) concluded that in a big oven heated by wood, the soft tissue of some individual parts of a body are in fact burned after one hour, but the calcined bones will remain intact. Bohnert *et al.* (1998: 16) observed that after a minimum of fifty minutes and a maximum of eighty minutes the torso of the body broke apart. In a study by Holden *et al.* (1995b: 30) an average adult body subjected to a fire temperature of 680°C, the face and arms were skeletonized after 15 minutes, the ribs and skull appeared after 20 minutes, and the lower extremities appeared after 35 minutes. There is evidence that the skeletal elements in ancient cremations failed to reach a temperature of even 300°C, which is considerably lower than the temperatures used in many of today's studies (Cattaneo *et al.*, 1999: 189).

One last point about cremation studies is the fact that cremated bone tends to survive better in the soil than normal or unburnt bone, for reasons that are not clearly understood, it appears to be connected with the structural changes to the mineral part of bone, after heating (Mays, 1998). The lack of an organic component in thoroughly incinerated bone may not be attractive to microorganisms which could be a factor it its survival in soil (Mays, 1998). Two other reasons given by Mays (1998) as to why archaeological cremated bone is more durable than experimentally burned bone are: 1) cremated bone regains its strength after firing due to uptake of water, 2) hydroxyapatite converts to betatricalcium phosphate when exposed to temperatures above about 800°C (Herrmann's "critical point"). Upon cooling there is a rapid re-reaction returning to hydroxyapatite on the uptake of moisture from the air and/or soil.

Macroscopic observations such as the color of the bone, fracturing and/or warping and shrinkage are the most common methods used to determine if a bone has been burned. Before we can begin to understand how the forces of heat and fire can alter bone we must first understand the biology and chemistry of bone.

The hardness and physical strength of bone comes from the extracellular deposition of calcium phosphate within a soft, fibrous, organic matrix (Posner, 1969). Bone mineral has been shown to consist of two calcium phosphate pools, one being a noncrystalline (amorphous) and the other being crystalline (apatite) (Posner, 1969). The main inorganic portion is made of carbonate apatite $(Ca,Mg,Na)_{10}[P,C)O_4]_6(OH,F)_2$, which is structurally related to the mineral hydroxyapatite ($[Ca_{10}(PO_4)_6(OH)_2]$) (Molin and Salviulo, 2002) as first observed using x-ray diffraction by WF Jong in 1926 (Posner, 1969). Carbon apatite mainly has variable contents of carbon but may also have, to a lesser extent, fluoro- and chloro-apatite modifications (Molin and Salviulo, 2002: 107). Both phases are composed predominately of calcium and phosphate. It appears that the amorphous portion predominates in early bone but is superseded by crystalline apatite as the bone matures (Posner, 1969). Approximately 35% of the dry, fat-free weight of mature bone in the organic fractions while the rest is calcium phosphate (Posner, 1969).

When bone is exposed to high temperatures, it undergoes physio-chemical processes that strongly influence morphologic diagnosis that can also lead to a trace element composition which may be different than that of the original bone (Grupe and Hummell, 1991: 177). An example of this is that at higher temperatures, elements originating in firewood or soft tissues may be incorporated into the bone mineral through crystal modification from the basic calcium phosphate mineral hydroxyapatite to beta-tricalciumphosphate (Grupe and Hummell, 1991: 186). Von Endt and Ortner (1984: 249) explain that since the internal structure of compact bone is relatively constant, the transmission of environmentally produced chemicals into bone, and the removal of reaction products from the bone are primarily related to the size of the bone and the distance the reactants must move in bone during diagenic processes.

Shepard (1956; cited in Shipman *et al.*, 1984: 321) concluded that bones and teeth probably undergo at least some of the same progressive stages of heating for minerals in ceramics, which has been well studied and documented. The six stages of heating are: dehydration, oxidation, reduction, inversion, decomposition, and fusion (Shipman *et al.*, 1984: 321). Dehydration occurs due to the breakage of hydroxyl bonds in the hydroxyapatite crystals, and removal of water molecules bound to the organic portion during heating (Shipman *et al.*, 1984: 321). The removal of moisture and the combustion of the organic portion of bone during heating leaves only the mineral or non-organic portion (hydroxyapatite) (Mays, 1998).

The chemical modification and loss of the organic portion of bone has been investigated using many different techniques including carbon, hydrogen and nitrogen (CHN) concentration monitoring, measuring glycine/glumatic acid (gly/glu) ratios and determining ammonia (NH_3) levels. Mineral changes have also been identified by using x-ray diffraction and infrared spectroscopy (Koon *et al.*, 2003: 1393). Taylor *et al.* (1995: 116) found that bones that were exposed to open fire had a characteristically significant increase in the relative amount of ammonia (NH_3) compared to normal diagenic reactions in the presence of water or water vapor. Taylor *et al.* (1995: 117) also used ion-exchange liquid chromatography with post-column derivatization using OPS (o-phthaldialdehyde) and florenscence detection to detect low levels of amino acids. This study by Taylor *et al.* (1995: 118) concluded that it is not currently possible to distinguish heating events from other biogeochemical effects using amino acid compositional criteria.

Shipman *et al.* (1984: 321) found that the decomposition of the organic portion of bone occurred between 360 and 525°C. A "rule of thumb" to remember when dealing with chemical reactions is that the rate of the reaction is doubled for each 10°C rise in temperature (Von Endt and Ortner, 1984: 249). They also found that bones heated at temperatures above 645°C produced x-ray diffraction patterns that were virtually identical to those ashed at 645°C. Heat-treatment of hydroxyapatite above about 600°C has been known to produce pyrophosphate as the acid phosphate groups in the apatite decompose (Holden *et al.*, 1995b: 41). Between 600 and 700°C, residual carbon from organic components is burned out leaving only the mineral phase of bone (Grupe and Hummell, 1991: 177). Above 800°C, hydroxyapatite changes to beta-tricalcium-phosphate (Grupe and Hummell, 1991: 178). Also note that this 600-800°C range corresponds with Herrmann's "critical level" for complete incineration (1977).

Although some cremation studies have used human bones, most use some sort of animal bone. Animal bones very closely resemble human bones and there are no major differences in the organic (40%) and inorganic (60%) components (Dunlop, 1978: 163). Shipman *et al.* (1984: 309) used goat and sheep bones because they are frequently present at archaeological sites. Von Endt and Ortner (1984: 249) used fresh bovine tibia that was obtained from a local butcher. Nicholson (1993) was concerned as to whether the results from other studies, such as the one conducted by Shipman *et al.* (1984) could be applied to the analysis of bones from other animal groups. To test this theory, Nicholson used bone from sheep, pigeon, salmon, herring, cod, haddock, and plaice and came up with comparable results.

Bone and tooth tissue initially have different appearances but the type of change they undergo is apparently dictated by the response of the constituent material to heating (Shipman *et al.* 1984: 321). Burning damage results in rapid transitions between damaged and undamaged bone surfaces (White, 1992). For example, tooth crowns tend to shatter due to the differing thermal properties of the enamel and dentine components (Mays, 1998). Collagen in heated bone is altered and leached so that the amino acid pattern tends to change from the collagen-like pattern (Taylor *et al.*, 1995: 116). Holden (1995b) noted that bone tissue taken from infants to young adults is thermodynamically more unstable than mature bone. Experiments by Shipman *et al.* (1984) showed that different bony and dental tissues undergo similar changes in color, microscopic morphology and size at different temperatures.

It is also important to know and understand which bones are likely to survive. Schwartz (1993) noted that in fetuses and infants the two densest bones of the body lie at the base of the skull (petrosal bones) during the first year of life. The petrosal bones and temporal bones will then fuse to form a larger mass. Mays (1998) found that the most commonly occurring fragments included the odontoid process of the axis vertebrae, the mandibular condyle and the petrous part of the temporal bone. Terminal phalanges, sesamoids and carpal often survive cremation without fragmenting (Mays, 1998). The most frequently surviving bones of the postcrania included the distal end of the humerus, the calcaneus, the talus, and the patella (Merbs, 1967: 501).

Both experimental and actualistic investigations have used color variation as a means for identifying and assessing the degree to which heat alters bone (Bennett, 1999: 2). Using color alone as criteria for burned bones is imprecise because of individual differences in the ability to perceive fine color and the fact that burnt bones may change color if they are buried (Shipman *et al.*, 1984: 312). Even though the assessment of color is subject to observer variation, the applicability and availability of this method warrants its use as a measure of heat exposure (Bennett, 1999: 2). At best, the color of a bone can only provide a general guideline to the temperature a bone has achieved (Nicholson, 1993: 425).

The color of cremated bone appears to reflect the amount of decomposition that has taken place within the bone rather than indicating the temperature of the fire (Mayne Correia, 1997). It is difficult to identify the specific temperature of the fire from bone fragments but one can possibly interpret the bone's position within the fire (Mayne Correia, 1997). Visual identification of bones by their color (especially black) is still very common even though it is well known that bones may very well change color when buried or as the result of contact with some minerals.

Bones that have been buried may have been discolored as the result of factors other that burning such as post-mortem funerary rites and/or soil conditions (Nicholson, 1993: 423). Franchet (in Nicholson, 1993: 423) observed that organic acids may be responsible for turning bone brown, dark blue or blue-gray, and iron oxides are responsible for orange and yellow tones. Iron phosphate causes light blue and green colors. Black colored bones may result from exposure to manganese and iron staining (Shahack-Gross *et al.*, 1997: 439-440).

A number of color/temperature scales have been published (e.g. Baby, 1954; Binford, 1963; Byers, 2002, Shipman *et al.*, 1984; Stiner *et al.*, 1995). Many of these scales are based on the Munsell Soil Color Chart (1954). The Munsell Soil Color Chart (1954) is a precise system of color notation. The use of this chart helps to minimize variation in individual interpretation of color and sets consistent a standard. Each color consists of hue, value and chroma. Hue is how related a color is to red, yellow, green, blue, and purple. Value indicates a colors lightness. Chroma notation indicates a color strength, or departure from a neutral of the same lightness. A typical notation of color using the Munsell Soil Color Chart would be 5Y8/2 (i.e. hue=5Y, value=8, and chroma=2).

Shipman *et al.* (1984: 312) note that hue begins in the yellow range, passes through reds and purples and ends up in diverse neutral hues above about 400°C. Value and chroma both begin high and drop abruptly, and diversify to high and low values at around the same temperature as hue.

Mayne Correia (1997) explains that the most common colors seen in burned bone are brown to blue-gray, black, gray, gray-white and chalk white. Some less common colors are green, yellow, pink and red. These different colors have biological and temperature related factors associated with them. Brown coloring may be associated with hemoglobin and/or discoloration from the soil (Mayne Correia, 1997). Black is a result of the carbonization of the bone and shades of gray from blue-gray to pale-gray result from the pyrolization of the organic components of the bone. White is the final stage of calcination, which is a result of the complete loss of the organic portion of bone, and the fusion of bone salts (Mayne Correia, 1997).

Baby's (1954) color/incineration category is among the simplest and most often cited. Baby divided burned bone into three categories:

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 are blackened in color from the incomplete destruction of organic mineral present in bone. Frequently, bits of charred periosteum are found adhering to the outer surface;
3) Non-incinerated, or "normal" bone – These fragments were not affected by the heat, but do show some smoking along broken edges.

Shipman *et al.* (1984: 312-313) came up with their own color chart but were more specific as to the temperature in which each of the colors were present. Their chart is divided into five stages:

Stage I (20-285°C), specimens are commonly neutral white, pale yellow and yellow.
Stage II (285->525°C), common colors are reddish brown, very dark gray-brown, neutral dark gray, and reddish-yellow.
Stage III (525->645°C), specimens are neutral black, with medium blue and some reddish-yellow appearing.
Stage IV (645-<940°C), neutral white predominates, with light blue-gray and light gray also present.
Stage V (940°C +), specimens are neutral white with some medium gray and reddish-yellow.

Stiner *et al.* (1995: 226) also published a chart of their own that is not as specific to temperature but instead correlates colors to codes to distinguish between degrees of burning.

0 – Not burned (cream/tan)
1 – Slightly burned; localized and < half carbonized
2 – Lightly burned; > half carbonized
3 – Fully carbonized (completely black)
4 – Localized < half calcined (more black than white)

5 - > half calined (more white than black)
6 – Fully calcined (completely white)

Shahack-Gross *et al.* (1997) and Stiner *et al.* (1995) have done studies that attempt to recognize burned bone using the HCl technique. Shahack-Gross *et al.* (1997: 439) found that the black color of bones, coupled with an infrared spectrum of the HCl-insoluble fraction of the bone organic matrix, can be used as a reliable criterion for distinguishing burned bones. Stiner *et al.* (1995: 229) found bones with burn codes of 2, 3 and 4-5 (see above chart) all produced insoluble fractions with infrared spectra characteristic of pyrolyzed material. Fully calcined bone (color code 6) had no soluble matrix and the HCl solution was clear, apparently because the entire internal matrix of the bone had been destroyed by heat. Using the HCl-insoluble fraction analysis techniques, along with macroscopic changes in internal bone color, Stiner *et al.* (1995: 234) concluded that one could more reliably diagnose burning damage on archaeological bone.

The development of cracking, checking and warping is also widely described but the conditions that produce these effects are incompletely understood. There appears to be a distinct difference in the type and directions of cracks of green or dry bones that are burned. Burned green or flesh-covered bone tends to have transverse fracture lines, irregular longitudinal splitting and noticeable warping (Eckert *et al.*, 1988: 190). Burning bone that is still covered in flesh is said to create splits along the surface that are deeper and more numerous than would be the case for burning a dry, defleshed bone (Schwartz, 1993).

Experiments by Baby (1954) also revealed distinctive differences between bones burned in the flesh and those burned dry. He agrees with Eckert *et al.* (1988) and

Schwartz (1993) that bones burned in the flesh tend to have deep transverse splitting or "checking" with predominate warping. Those that were burned dry showed deep longitudinal fractures with limited warping. Based on his experiments he was able to determine that the Hopewell had cremated their dead in the flesh (Baby, 1954).

Binford (1963) examined cremations from three Michigan sites and concluded that all of them contained the burning of fresh bone and had been incinerated individually as opposed to communal pyres. Binford's findings confirmed those of Baby; that dry bones can be distinguished from those of green or flesh covered bone. He observed the presence of straight transverse cracks in dry bone and curved, transverse cracks in fleshed bone. Binford also showed that the fracture patterns on dry cremated bones were the same, regardless if the bone was recent or ancient (Thurman and Willmore, 1980-81).

Thurman and Willmore (1980-81: 281) also noted that bones burned "in the flesh" showed a very different pattern than those that were defleshed or dry. What they observed was that as the flesh on the bone was consumed, so was the bone itself. They came to the conclusion that serrated, transverse fractures that penetrate deep into or totally through bone, together with cracking accompanied by warping indicates in-flesh cremation, while serrated fractures near epiphyses but otherwise parallel-sided fractures through bone and less pronounced warping is more typical of cremated green (recently defleshed) bone. They did not find extensive warping in green bone as previously reported by Baby (1954) and Binford (1963) but did find that much of the checking did go all the way through the bone. Buikstra and Swegle (no date, cited in Mayne Correia, 1997) claim, "the presence of deep transverse cracks clearly is not sufficient evidence for identifying fleshed cremations."

Shrinkage may be associated with the structural changes that occur to the mineral hydroxyapatite. These structural changes take the form of changes in crystallinity (Mays, 1998). One possible explanation previously suggested by Herrmann (1977) is that the ultrastructure of bone dictates the amount of shrinkage that is possible at a given temperature (Shimpan *et al.*, 1984).

Herrmann (1977) laid out four factors that affect shrinkage-the distribution of compacta/spongiosa and of the different types of lamellar components; the temperature of exposure; the mineral content of the bone (mg HA/ml); and aspects of the mineral content of bone mineral. Based on these four criteria Herrmann suggests three phases of shrinkage (150-300°C, 750-800°C {1-2% shrinkage}, 1000-1200°C {14-18% total shrinkage}) (Mayne Correia, 1997). Others (Ubelaker and Scammell, 1992; Hummel and Schutkowsi; Dokkadak (cited in Mays, 1998) have all studied the effects of shrinkage due to fire and their results are comparable to those of Herrmann. Ubelaker and Scammell's (1992) results suggest that shrinkage of bone varies from 1-25%, depending on bone density and temperature and duration of the fire. Hummel and Schutkowsi found shrinkage of up to 30% (cited in Mays, 1998) and Dokaladal (cited in Mays, 1998) found shrinkage of up to 15% in cremated individuals.

A possible reason for the variation between the previously mentioned studies is that the mean percentage of shrinkage is not constant at all temperatures (Shipman *et al.*, 1984: 320). Many will agree (Ubelaker and Scammell, 1992; Bradtmiller and Buikstra, 1984; Shipman *et al.*, 1984) that bone shrinkage occurs between 700-900°C as previously put forth by Herrmann (1977) as the "critical level". Shrinkage presumably occurs as a occurs as a direct result of the fusion of mineral crystals that Herrmann observed at 700-800°C (Bradtmiller and Buikstra, 1984: 536).

Realistic investigations have addressed incremental temperature related changes in surface morphology, such as shrinkage and fracturing, as indicators of pre-incineration condition and temperature of heating (Bennett, 1999: 2). Several metric methods of estimating the living stature have been applied to incinerated remains (Grevin *et al.*, 1998: 131). These methods are based mainly on the correlation between the diameter of femoral, humeral and radial heads, and the length of the corresponding diaphysis (Grevin *et al.*, 1998: 131). For instance, Shipman *et al.* (1984: 310) accounted for shrinkage by taking four different measurements (maximum length of the lateral aspect, maximum length of the medial aspect, minimum longitudinal circumference, taken near the midline, and minimum corpus circumference as measured in the diastema). These measurements were taken before and after heating, is summarized by the following equation: [(original dimension – altered dimension) / original dimension] x 100 (Shipman *et al.*, 1984) in order to determine pre-incineration stature.

Superficially, burnt bone may imitate bone weathering (White, 1992). Weathering and burning cause similar alterations to bone such as cracking, cortical exfoliation, color change, an increase in crystal size and organization, and a loss of collagen and modification to the remaining amino acid composition (Koon *et al.*, 2003: 1393). A recent study failed to discriminate between boiled and buried bone (Koon *et al.*, 2003: 1393).

A study by Stiner *et al.* (1995) concluded that weathering could rapidly induce changes in bone crystals and a loss of bone matrix that is similar to the effects of fire.

The study maintains that some microscopic transformation caused by weather can occur rapidly, likely within the first year or two of exposure, and then stabilize. These microscopic changes do not directly correspond to the visible degrading of bone that one normally associates with weather damage. Crystalline changes in modern bone caused by weathering partly overlap with those caused by fairly low temperature heat, up to complete carbonization (Stiner *et al.*, 1995: 233). Stiner *et al.* (1995: 233) concluded that diagenic processes could achieve the same effects in unburned bones buried for thousands of years as an experimental fire can achieve instantly.

A study by Bennett (1999) attempted to characterize bone burned following deposition and burial and more specifically to determine if bone located in deposits can be burned by a present day surface fire. Bones buried at a depth of 5 cm exhibited burning to the point of carbonization and those buried at 10 cm showed evidence of thermal alteration. The data indicated that bone situated in a subsurface matrix could be altered initially or long after deposition. Bennett (1999: 5) concluded that alteration of bone is influenced by the interaction of several factors including pre-incineration condition, intensity of heating, duration of exposure and the type of sediment. This finding indicates that the traditional assumption that bone is burned through direct exposure to fire or flame must be re-evaluated.

At very low magnification little structural difference is observed between an unheated bone sample and one that has been heated in the temperature range of 200-1400°C, except for the occurrence of shrinkage and fractures (Holden *et al.*, 1995b: 43). Observations under a light microscope by Holden *et al.* (1995a: 18-19) revealed that small fragments were mostly light gray to white, but larger fragments displayed color changes ranging from black through shades of gray to white. In larger bone fragments, the color of the outer regions of cortical bone was white and changed to gray in the mid-cortical region. The inner cortical bone adjacent to the medullary cavity was black. Holden *et al.* (1995a: 19) also observed that the outer surface of the cortical bone exhibited fractures and a slight degree of distortion when compared to unheated bone.

Light microscope observations by Forbes' (1941, cited in Mayne Correia, 1997) included the disappearance of the canaliculi as the lamellae became coarse and granular. The lacunae changed from flat and distorted to hazy outlines, the lamellae gradually disappeared, leaving a uniformly granular matrix with Haversian canals throughout. In this phase the Haversian systems decreased in size, but the canals increased in diameter and filled with debris.

Nicholson (1993: 415-416) recognized a number of temperature related features using a light microscope. Among the most informative was the development of black, tar-like, carbon-rich "char" at 300-500°C. This "char" could be recognized by its glass-like form at the lower end of the temperature range and by peeling surface films at the higher end of the range. Nicholson (1993: 427) also found that for observing cracking and the presence of char, a standard light microscope was most useful in recognizing these features that occur in bone that is heated to lower temperatures (200-700°C). If melted trabeculae (intersecting osseous bars in cancellous bone) are observed, it is possible that the bone was heated to above 700°C (Nicholson, 1993: 427).

Light microscope observations of heat treated bone revealed large radial fractures that spread from the outer cortical bone into the mid-cortical regions (Holden, 1995a: 23).

These observations also revealed that there was very little change in the structure on the bone with heat-treatment up to 1400°C (Holden, 1995b: 40).

Histological examinations of cremated bones are difficult because of the structural changes caused by heat (Herrmann, 1977). The main area of focus so far concerning change has been the osteons or Haversian systems. An osteon is a central canal containing blood capillaries and the concentric osseous lamellae around it occurring in compact bone.

Much of the work being done is exploring how bone microstructure changes under burning conditions and determining whether osteons change in appearance or whether osteons or other structures change in size (Bradtmiller and Buikstra, 1984: 535). Both Cattaneo *et al.* (1999) and Shipman *et al.* (1984) agree that osteons shrink when subjected to heat, but Brandtmiller and Buikstra (1984: 537) found that osteons in burned bone were uniformly larger than those of unburned bone. They offer three possible explanations as to why ostoens in their study were larger rather than smaller. The first explanation suggests that the bone may expand slightly before it shrinks and if the burning of the bone is stopped before it shrinks, the osteons will be larger than expected. The second suggests that the bone may shrink in its external dimensions, but because of some rearrangement of microstructural elements the osteons themselves may actually increase in size. The third possible explanation is that there was a sampling problem and the bone and osteons actually did shrink as expected.

Two difficulties with studying burned bones are being able to identify 1) if bones are human or non-human and 2) determining of age if possible. To determine whether incinerated bone is human or non-human (if unidentifiable by visual determination), one needs to look at the osteon form, distribution pattern and the occurrence of plexiform bone, as it is present in other mammals but not in humans (Cattaneo *et al.*, 1999: 187). The standard data indicates that the most important discriminating factor is the maximum and minimum diameter of the Haversian canal (Cattaneo *et al.*, 1999). Determining age using osteon counting can be used with both burned and unburned bones. According to Shipman *et al.* (1984: 308-309), osteons remain visible after heating to temperatures below 800°C (Herrmann's "critical point"), which means techniques that rely on the density of osteons can be applied to burned bone.

On the basis of chemical, x-ray diffraction, and electron microscope studies, it has been assumed that the inorganic component of bone tissue is a poorly crystallized calcium phosphate resembling, but not identical to, the structure and composition of the mineral hydroxyapatite (Posner, 1969). Fresh bone normally consists of 60-70% (by weight) dahllite (carbonate apatite) crystals (Stiner *et al.*, 1995: 227). Molnar, Ascenzi and Bonucci as cited in Posner (1969) suggest that bone crystals are composed of chains of microcrystals that are fused together in an end-to-end relationship. In living bone these crystals tend to be very small, but upon heating their size begins to increase (Mays, 1998). In the temperature range of 600 to 1600°C, changes in the size and morphology of crystals begins to be seen (Holden *et al.*, 1995b: 41).

Direct observation of the crystalline structure of bone can be made by electron microscopy and, if the crystals are large enough, by using a light microscope (Posner, 1969). Observations of bone apatite crystals using electron microscopy has not always supported conclusions reached by using x-ray diffraction analysis (Posner, 1969).

Biological factors are important in determining the size, shape and orientation of bone crystals (Von Endt and Ortner, 1984). Scanning electron microscopy (SEM) analysis assumes that the surface morphology of bone is not altered by taphonomic processes (Nicholson, 1993: 412). Comparisons by Stiner *et al.* (1995: 234) show that the signatures of crystallinity of bones altered by weathering, burning and fossilization partly overlap. They also observed that the crystal lattice of bones might change if they are buried in sediments for long periods of time. Diagenesis may produce changes in the crystal structure similar to those produced by burnt bone but SEM analysis by Shipman *et al.* (1984: 321) did not reveal the morphological changes that accompany heating to high temperatures. SEM analysis by Nicholson (1993: 423) concluded that most specimens exhibited a surface similar to that expected for fresh or lightly heated bone.

Intrinsic factors that produced post-mortem changes in bone were the spontaneous rearrangement of the crystalline matrix and the action of internal water on the proteins of bone (Von Endt and Ortner, 1984: 248). These changes continued with minimal effects from extrinsic environmental factors.

The amorphous (organic or noncrystalline) portion of bone mineral is marked by a distinct rounded, doughnut-shape while the crystals of bone apatite exhibit a straight-edged, solid needle-shape (Posner, 1696). There are two viewpoints on the shape of bone crystals. Wolpers (in Posner, 1969) describes them as having a needlelike shape with a size of 3060 Angstroms in width and 400-1000 Angstroms in length. Posner (1969) also noted that Molnar and Ascenzi and Bonucci reported that bone crystals were only 30-50 Angstroms in thickness, but ranged from less than 50 Angstroms to well over 1000 Angstroms in length. The platelike crystals as described by Robinson and Watson and by Johansen and Parks (in Posner, 1969) had typical dimensions of 400 x 200-350 x 25-50 Angstroms.

Posner (1969) described the mean size of apatite crystals in dental cementum and dentin is comparable to that of bone, although enamel crystals are at least an order of magnitude larger in all dimensions. The average length of enamel crystals is about 1400 Angstroms while the other two dimensions of the needlelike crystals are about 800 Angstroms each (Posner, 1969).

In the low temperature range (400-645°C) bone crystals tend to exhibit a gradual increase in size with an increase in temperature (Shipman *et al.*, 1984: 315-316). Experiments by Holden *et al.* (1995b: 38) observed that prolonged heat treatment of 12 hours at 400°C resulted in the removal of the endosteum of the bone. This same time/temperature research indicated that the individual fibers frayed away from the main fiber bundles (they also noted that the degree of fraying was directly related to the age of the person in which the bone had been taken). Mays (1998) found that up to 525°C, there is a gradual increase in the crystal size as observed using x-ray diffraction. Between 525°C and 645°C, Mays (1998) found that there was an abrupt transition to a much more crystalline structure with a larger individual crystal size and that little or no change appears to occur above 645°C. Shipman *et al.* (1984: 315) agree with this statement as they found that with x-ray diffraction patterns, there was a distinct difference in crystal size between bone heated to above 645°C and those heated to a temperature lower than 645°C. Holden *et al.* (1995b: 39-40) also heated samples at 600°C for 12 to 24 hours and observed an improvement of the hexagonal and spherical crystal morphology but the size of the crystals did not significantly increase.

Above about 650°C a solid state recrystallization occurs (Stiner *et al.*, 1995: 227). Holden *et al.* (1995a) observed that the size of the spherical-type crystals in the 600°C temperature range exhibited a size of 0.06 $\pm$ 0.007 microns. The hexagonal-shaped crystals ranged in size from 0.25 $\pm$ 0.07 to 0.41 $\pm$ 0.09 microns in the temperature range of 800-1000°C. Bone heated to these high temperatures exhibit distinctive enlarged mineral structures (Nicholson, 1993: 421). At these temperatures several distinct patterns occurred, including rod-shaped structures, spheres with a "knitted" appearance, and irregular, globular structures, or a combination of these (Nicholson, 1993: 421).

Shipman *et al.* (1984: 312-313) proposed five stages to describe bone tissue when using the SEM. As with the stages using color, these stages are also set by temperature. The first stage ranges from 20-<185°C which describes the tissues as normal. The second stage ranges from 185-<285°C and describes the tissues as showing increased roughness. The third stage (285-<440°C) is characterized by a glassy and very smooth appearance. In stages four (440-800°C) and five (800-940°C) the tissues first exhibit a "frothy and fleecy" appearance that gradually come together into smooth-surface globules.

Bones experimentally burned by Holden *et al.* (1995a: 19) exhibited a white outer cortex, a gray mid-cortex and black, inner medullary region. The outer regions of the cortex contained crystals with a hexagonal-shaped morphology that occasionally had smaller spherical crystals attached to the surface. As the color of the bone gradually changed from white to gray, the hexagonal crystals became progressively more spherical and the crystal size was found to decrease. The average size of these spherical crystals was ~0.060 $\pm$ 0.007 microns. Holden *et al.* (1995a: 21-23) also noted crystals with other distinctive shapes such as rhombohedral, rosette, platelet on the free surface of the

Haversian canal. The rhombohedral-type crystal ranged in size form 0.26 to 5.30 microns, rosette-type crystals from 3.20 to 12.60 microns and the platelet-type crystals ranged in width from 0.10 to 0.50 microns and a length of 10^{-6}.

In another study by Holden *et al.* (1995b), each crystal morphology was noted along with the maximum temperature reached by the fire. High fire temperatures of 800 to 1600°C were maintained for two hours. In the temperature range of 800 to 1400°C, crystals with a spherical morphology similar to those seen in the 600°C range are present along with new hexagonal and prismatic crystals. The size of the hexagonal crystals were found to increase with the rise in temperature. In the 800 to 1200°C range, there was no significant change in size or shape of either the hexagonal or spherical shaped crystals. Between 1000 to 1400°C, the hexagonal crystals began to fuse or sinter. Also in this temperature range new rhombohedral-shaped crystals with a diagonal length ranging from 0.300 to 6.0 microns begin to emerge. These high temperatures also produce the rosette and platelet-like crystals as well as some irregulars. These types of crystals were all present in a range of sizes and either as clusters or individual crystals.

At temperatures above 1400°C, Haversian canals and osteocyte lacunae begin to lose their integrity, while the lamellar structure was lost at around 800°C (Holden *et al.*, 1995b: 38). At around 1600°C, all structural features become completely destroyed due to complete melting and subsequent recrystallization of the bone mineral upon cooling (Holden *et al.*, 1995b: 38).

Bone exposed to very high temperatures causes fusion or sintering of mineral crystals and the characteristic shrinkage of cremated remains (Herrmann, 1977). Sintering is both a physical as well as chemical change (Nicholson, 1993: 123). There is some discrepancy as to when the onset of sintering begins. The study by Shipman *et al.* (1984: 321) observed that sintering, the melting of hydroxyapatite crystals, occurs above 800°C. Holden *et al.* (1995b: 34) observed sintering in small localized areas at around 1000°C.

These high sintering temperatures induce hydroxyapatite crystal growth and fusion; it increases the crystallinity and decreases the total porosity and pore size of the bone (Rodrigues *et al.*, 2003). The average diameter of hydroxyapatite grains is 0.5 to 10 microns and the average diameter of decrease of the microscopic pores between hydroxyapatite grains ranged from 0.1 to 5 microns, with the diameter decreasing with the increase of sintering temperature (Rodrigues *et al.*, 2003). Rodrigues *et al.* (2003) recognized some secondary phases that are formed during the hydroxyapatite sintering process that are related to its original Ca/P ratio, chemical composition and sintering temperature. Rodrigues *et al.* (2003) concluded that sintering temperature had an important effect on both morphological characteristics and the microporosity of the bovine hydroxyapatite.

Chapter 3: Nature of Fire

Many fires that achieve extremely high temperatures are fueled by some sort of accelerant. Gasoline has been found to be the most widely used accelerant (Brettell, no date). In 1990, 287 murders were found to be the result of fire (Ubelaker and Scammell, 1992). The following chart is from the most recent publication (2002) of the Uniform Crime Report put out by the Federal Bureau of Investigation indicating murder victims by weapon from 1998 to 2002.

Without the addition of gasoline or some other flammable liquid, experiments have shown that house fires usually do not exceed 1600°F (871°C) (Bass and Jefferson, 2003: 77-78). In a fire that is fueled by gasoline or some other flammable accelerant, fire temperatures can reach as high as 2000°F (1093°C) (Bass and Jefferson, 2003). When bones are burned at this high of a temperature, they will undergo both chemical and structural changes. A body that is saturated with gasoline or another accelerant may lead to total or partial cremation, but usually the surface of the body is burned, leaving the body a charred mass (Eckert et al, 1988: 200). Many times the fire will be extinguished by the fire department or some other source before complete cremation has taken place.

Table 1-Uniform Crime Report

Weapons	**1998**	**1999**	**2000**	**2001**[1]	**2002**
Total	**14,209**	**13,011**	**13,230**	**14,061**	**14,054**
Total Firearms:	9,220	8,480	8,661	8,890	9,369
Handguns	7,405	6,658	6,778	6,931	7,176
Rifles	546	400	411	386	480
Shotguns	626	531	485	511	476
Other Guns	16	92	53	59	74
Firearms, type not stated	627	799	934	1,003	1,163
Knives or Cutting Instruments	1,890	1,712	1,782	1,831	1,767
Blunt Objects (clubs, hammers, etc.)	750	756	617	680	666
Personal Weapons (hands, fists, feet, etc)[2]	959	885	927	961	933
Poison	6	11	8	12	23
Explosives	10	0	9	4	11
Fire	**132**	**133**	**134**	**109**	**104**
Narcotics	33	26	20	37	48
Drowning	28	28	15	23	18
Strangulation	213	190	166	153	143
Asphyxiation	99	106	92	116	103
Other Weapons or weapons not stated	869	684	799	1,245	869

[1] The murder and non-negligent homicides that occurred as a result of the events of September 11, 2001, are not included.

[2] Pushed is included in personal weapons.

Initial examination of a fire scene should be treated as a potential crime scene and should include careful investigation for the presence of an accelerant such as gasoline or other flammable liquids. The investigation should include whether nor not the odor of an accelerant is present and samples of skin, clothing, or wood should be collected and tested for the presence of an accelerant (Eckert *et al.*, 1988: 194). Cremation to cover up a homicide should always be taken into consideration when examining fire victims, especially if the victim shows additional injuries such as gunshot wounds or sharp or blunt force injuries (Bohnert and Rothschild, 1984: 201).

The detection of arson accelerants is most often accomplished using a headspace sampling technique combined with Gas Chromatography (GC) and/or Gas Chromatography/Mass Spectrometry (GC/MS) (Brettell, no date). The Federal Bureau of Investigation does gas chromatographs on cars, skin and clothes of suspects to determine what kind of combustible agent started a fire (Ubelaker and Scammell, 1992). In order to identify accelerants, as many potential accelerants as possible must be analyzed to come up with a standard or "fingerprint" of each accelerant (Brettell, no date). These "fingerprint" chromatographs are then compared to those produced from suspicious fires in an attempt to identify the accelerant (Brettell, no date).

There are three basic types of headspace sampling that is used for sample preparations: Normal Dynamic Headspace, Direct Thermal Analysis and Short Path Thermal Desorption System. The Normal Dynamic Headspace procedure involves purging the container with an inert gas and collecting the purged volatiles on a solid sorbent and then eluting them with an organic solvent (Brettell, no date). Direct Thermal Analysis allows for the analysis of items such as arson wicks, wood and fibers to be placed directly in the sampling tube and the volatiles are then purged directly into the GC injection port (Brettell, no date). The sample size for this technique ranges from 1 mg up to 500 mg and most importantly, none of the sample is lost in preparation (Brettell, no date). The last method, Short Path Thermal Desorption System, allows for the analysis of arson samples by desorbing samples previously collected on absorbent resins directly into the gas chromatograph injection port for later analysis by conventional gas chromatograph detectors or by means of mass spectrometers (Brettell, no date).

Chapter 4: Materials and Methods

The bones used in this study were bovine bones obtained from a local butcher shop. All of the bones had at least some flesh still adhering and are considered "green" or "in-flesh" for the purpose of this study. The bones chosen for this study were the hock (the joint between the distal end of the tibia and the proximal end of the metatarsus), ribs, vertebrae (also known as chine bones, which are the split vertebrae, resulting from the longitudinal division of the carcass into sides), scapula, sternum and part of the pelvic girdle. Also note that some of the ribs were still attached to the vertebrae and some were not. The hocks from this particular butcher shop contained the distal end of the tibia, astragalus, calcaneus, distal fibula and the fused central and fourth tarsals. The following table lists what bones were present in each fire.

Table 2 – Bones Present During Fire

Bone Present	Fire #1	Fire #2	Fire #3
Sternum	2	0	0
Astragalus	2	2	2
Calcaneus	2	2	2
Scapula	1	0	1
Vertebrae	11	10	0
Fused Central & 4th Tarsal	1	1	1
Distal Tibia	2	2	2
Distal Fibula	1	1	1
Pelvis	0	1	0
Sacrum	0	1	0
Tarsal Bone	0	0	1
Proximal Tibia	0	0	1

Three different fires were used in obtaining the data. Each fire consisted of a mixture of Aspen (Populus tremula), Quakey (Populus tremuloides), and Willow (Salix babylonica) trees. The wood was taken from a large pile that was going to be burned as a slash burn in the spring. The wood was very dry which made it ideal for burning. Each fire was built to approximately the same size using a pyramid building shape. The bones were placed in each fire randomly, with some being in the middle and some along the outer perimeter.

One fire was to represent a traditional modern campfire, one started with charcoal lighter fluid, and one with gasoline. These accelerants were used because they are common household items that are frequently used to cover up crimes in the form of arson. The modern campfire was used as the control in this study.

The modern-day fire was started using paper and wooden matches. The pre-burning dimensions of the fire were 4'4" x 4'3" x 2'3". This fire was allowed to burn and get a few coals before the bones were put in. The reason that this was done is because from a forensic stand point, one would likely start the fire before putting a body in because a campfire started in this manner takes some time to get going and heated up to the point that it could do damage to a body. Once the fire got going all of the bones were placed in it. This fire contained two hocks, two ribs attached to the spine, two ribs unattached, a scapula, eight sagitally sectioned vertebrae and a sternum.

The second fire was started using charcoal lighter fluid. All of the bones were placed inside the wood in different locations before the fire was set. The pre-burning size of this fire was 4'2" x 3'9" x 2'8". This fire contained two hocks, three ribs attached to the spine, four ribs unattached and part of the pelvic girdle. Once all the bones were in place, the wood and bones were saturated with charcoal lighter fluid. A wooden match was thrown in to start the fire.

The third fire was started using gasoline. Once again all the bones were placed inside the wood in different locations before the fire was set. The pre-burning dimensions were 4'5" x 4'7" x 2'2". The bones that were placed in this fire were two hocks, three ribs attached to the spine, four ribs unattached, proximal end of a tibia and a broken scapula. The bones and wood were then saturated with gasoline. Again, the fire was started with a wooden match.

Each fire was allowed to burn until the heat began to rapidly decrease. No additional wood or accelerant was added after the fires were initially started nor were any of them stoked during burning. Measurements of the fire temperature were taken at approximately 15-minute intervals using a Scott Eagle II Thermal Imaging camera. The maximum temperature that the thermal imaging camera could capture was 600°C or 1112°F. The camera was pointed in the direction of the middle of the fire, from the same spot each time, to get the hottest temperature reading, though through the camera display, one could see the bones were not as hot as the fire. Temperatures of the bones themselves could not be determined because of the interference of the heat from the surrounding fire. Pictures were also taken using a Kodak Advantix F600 every 10 to 15 minutes to record any changes in color or fragmentation.

After the heat of the fire began to rapidly decrease, any large sticks or logs were carefully removed to give the fire a chance to cool down so the recovery process could begin. Once the fire had cooled down sufficiently to begin recovery, all bones and as many bone fragments as possible were collected from the fire and laid aside so as to give them more time to cool off before packaging. A sieve was not used because the bone fragments that were too small to collect by hand were easily broken and turned to ash. Most, if not all, of the smallest fragments were rib fragments and were not crucial to the results of this study and were not collected. All bones and bone fragments were then put into paper bags and labeled according to which fire they had been in.

Two samples from each fire (one astragalus and one calcaneus) were taken to the University of Montana Electron Microscopy Facility. Small fragments from each sample were mounted on SEM stubs using copper tape. The samples from the gasoline fire were sputter coated using a Pelco Model 3 Sputter Coater 91000 with a combination of platinum and gold approximately two to three Angstroms thick and then mounted on a SEM stub using copper tape. Each sample was then analyzed using a Hitachi S-4700 Scanning Electron Microscope. At least one sample from each fire was run through an energy dispersive system (EDS) to detect elements present in the sample. Measurements and analyses were done using the Quartz PCI database. Any time that the sample was not being analyzed it was placed in an Isotemp Vacuum Oven Model 280A Dessicator.

Chapter 5: Results

In tables 3-5 and Figures 1-3, the fire labeled as number one is the fire that no accelerant, fire number two contained charcoal lighter fluid and gasoline was used on fire number three.

Tables 3-5 and Figures 1-3 demonstrate the temperature of each fire and what time each temperature was taken.

Table 3 - Fire #1 – No Accelerant

Time	Temp. °F	Temp. °C
2:10 pm	Start	Start
2:28 pm	≥ 1112	≥ 600
2:42 pm	≥ 1112	≥ 600
2:53 pm	≥ 1112	≥ 600
3:02 pm	≥ 1112	≥ 600
3:16 pm	700-900	371-482
3:28 pm	~ 550	~ 288
3:42 pm	650-700	343-371
3:59 pm	550-650	288-343
4:16 pm	~ 650	~ 343
5:21 pm	Complete	Complete

Figure 1 – Graph of Fire #1 Temperature

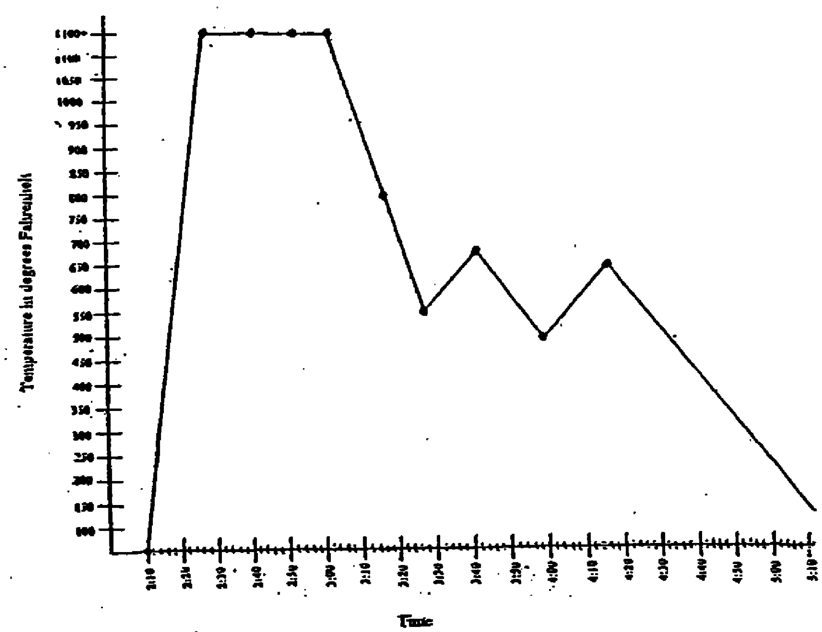


Table 4 - Fire #2 – Charcoal Lighter Fluid

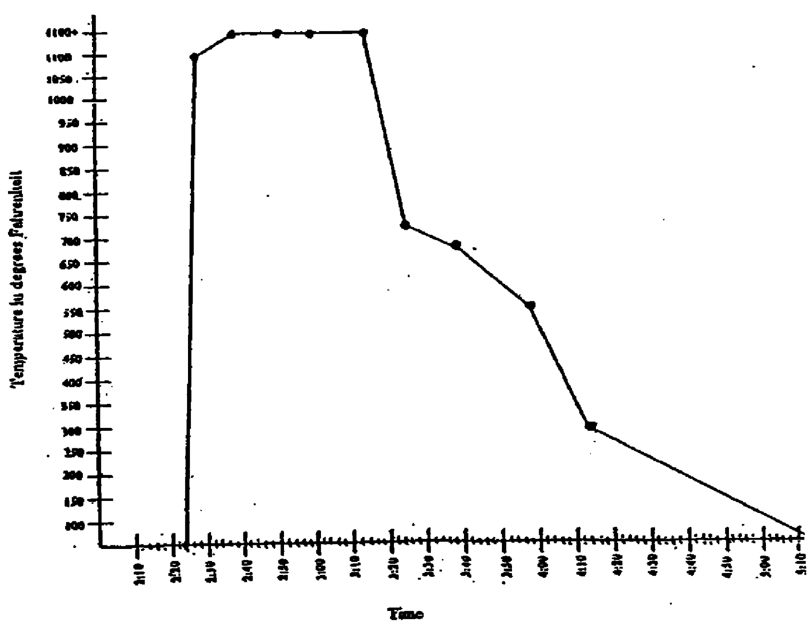
Time	Temp. °F	Temp. °C
2:25 pm	Start	Start
2:27 pm	≥ 1112	≥ 600
2:41 pm	≥ 1112	≥ 600
2:52 pm	≥ 1112	≥ 600
3:01 pm	700-800	371-427
3:14 pm	750	399
3:26 pm	614-801	323-427
3:41 pm	650-730	343-388
3:58 pm	450-550	232-288
4:15 pm	550-630	288-332
4:56 pm	Complete	Complete

Figure 2 – Graph of Fire #2 Temperature

Table 5- Fire #3 – Gasoline

Time	Temp. °F	Temp. °C
2:24 pm	Start	Start
2:27 pm	1100	593
2:39 pm	≥ 1112	≥ 600
2:50 pm	≥ 1112	≥ 600
3:00 pm	≥ 1112	≥ 600
3:12 pm	≥ 1112	≥ 600
3:25 pm	~ 730	~ 388
3:39 pm	650-720	343-382
3:58 pm	~ 550	~ 288
4:14 pm	250-330	121-166
4:31 pm	Complete	Complete

Figure 3 – Graph of Fire #3 Temperature



All of the bones from each fire were visually analyzed and put into categories according to those set forth by Baby (1954), Shipman *et al.* (1984) and Stiner *et al.* (1995) as shown in Tables 6-14. These three were chosen because each uses slightly different criteria for the determination of complete calcination and I wanted to see how well they would correlate.

The fragments that resulted from the unaccelerated present day campfire showed both longitudinal and transverse fracturing. The two fragments from the sternum showed slight superficial transverse cracking. The astragali bones displayed mostly transverse cracking with some curved fractures around the articulation edges. Both of the calcaneus bones were broken at the epiphyses and exhibited mostly transverse cracks along with a few longitudinal. The scapula showed deep longitudinal cracks that extended all the way through the cortex along with some superficial checking on the surface.

Of the two distal tibias, the epiphyses broke off of one of them. They both showed mostly longitudinal cracks with some being superficial and some extending all the way through the cortex. Curved cracks were also noted along the epiphyses. The three vertebrae that were not sagitally sectioned showed both longitudinal and transverse cracks although they were mostly superficial. The eight vertebral fragments that were sagitally sectioned were almost identical to those that were not. The rib fragments that were collected showed both longitudinal and transverse cracking as well as some curved cracks. Most of the ribs were broken in the transverse direction but only cracked in the longitudinal direction along the axis.

In Fire #2 both astragalus bones showed mostly transverse cracking along with a few longitudinal cracks. The two calcaneus bones exhibited mostly transverse fractures with some longitudinal. One of them was broken at the epiphyses and still had charred tissue attached. Each of the distal tibias showed deep longitudinal cracks with curved cracks along the articulated surface. The pelvis (iliac crest and portions of the acetabulum and ischium) exhibited mostly longitudinal fractures. The transverse cracks that were present were deep enough to split the pelvic bone along the transverse axis. The sagitally cut vertebrae had both longitudinal and transverse cracks but both were light and fairly superficial. Recovered ribs also exhibited both longitudinal and transverse cracks and most were broken along the transverse edge. A few also displayed slight warping.

The distal tibia of the gasoline fire displayed mostly longitudinal cracks as well as a few transverse. The cracks in each astragalus were mostly longitudinal and showed some superficial checking. Both of the calcaneus bones were broken along the epiphyses. Most of the cracks exhibited here were transverse but there are a few that extend all the way through the cortex. There were not as many ribs recovered from this fire than either of the other two, the ones that were recovered exhibited both longitudinal and transverse fractures. They show some warping on the smaller fragments and are usually broken along the transverse axis.

Table 6 Fire #1 – using Baby (1954)

Fragment	Completely Incinerated*	Incompletely Incinerated**	Non-Incinerated***
Sternum 1		X	
Sternum 2		X	
Astragalus 1	X		
Astragalus 2	X		
Calcaneus 1	X		
Calcaneus 2	X		
Scapula	X		
Vertebrae 1		X	
Vertebrae 2		X	
Vertebrae 3		X	
Fused Central & 4th Tarsal	X		
Distal Tibia 1	X		
Distal Tibia 2	X		
Sagitally cut Vertebrae 1	X		
Sagitally cut Vertebrae 2	X		
Sagitally cut Vertebrae 3	X		
Sagitally cut Vertebrae 4	X		
Sagitally cut Vertebrae 5	X		
Sagitally cut Vertebrae 6	X		
Sagitally cut Vertebrae 7	X		
Sagitally cut Vertebrae 8	X		
Distal Fibula	X		

*Completely Incinerated – fragments range from light gray, blue-gray, to buff in color and show deep "checking," diagonal transverse fracturing and warping.
**Incompletely Incinerated – 'Smoked.' Fragments blackened in color from the incomplete combustion of organic material present in the bone. Frequently bits of charred perisosteum are found adhering to the outer surface.
***Non-incinerated – "Normal bone." Fragments not affected by heat, but do show some smoking along broken edges.

Table 7 Fire #1 – using Shipman *et al.* (1984)

Fragment	I	II	III	IV	V
Sternum 1		X			
Sternum 2			X		
Astragalus 1				X	
Astragalus 2				X	
Calcaneus 1					X
Calcaneus 2					X
Scapula				X	
Vertebrae 1		X			
Vertebrae 2		X			
Vertebrae 3		X			
Fused Central & 4th Tarsal					X
Distal Tibia 1				X	
Distal Tibia 2			X		
Sagitally cut Vertebrae 1				X	
Sagitally cut Vertebrae 2				X	
Sagitally cut Vertebrae 3				X	
Sagitally cut Vertebrae 4				X	
Sagitally cut Vertebrae 5				X	
Sagitally cut Vertebrae 6				X	
Sagitally cut Vertebrae 7				X	
Sagitally cut Vertebrae 8				X	
Distal Fibula				X	

Stage I (20-285°C) – commonly neutral white, pale yellow, and yellow.

Stage II (285<525°C) – common colors reddish brown, very dark brown, neutral dark gray and reddish-yellow.

Stage III (525<645°C) – neutral black, with medium blue and some reddish-yellow appearing.

Stage IV (645<940°C) – neutral white predominates, with light blue-gray and light gray also present.

Stage V (940+°C) – neutral white with some medium gray and reddish-yellow.

Table 8   Fire #1 – using Stiner *et al.* (1995)

Fragment	0	1	2	3	4	5	6
Sternum 1					X		
Sternum 2						X	
Astragalus 1						X	
Astragalus 2						X	
Calcaneus 1							X
Calcaneus 2							X
Scapula						X	
Vertebrae 1				X			
Vertebrae 2					X		
Vertebrae 3						X	
Fused Central & 4th Tarsal							X
Distal Tibia 1						X	
Distal Tibia 2					X		
Sagitally cut Vertebrae 1						X	
Sagitally cut Vertebrae 2						X	
Sagitally cut Vertebrae 3						X	
Sagitally cut Vertebrae 4						X	
Sagitally cut Vertebrae 5						X	
Sagitally cut Vertebrae 6						X	
Sagitally cut Vertebrae 7						X	
Sagitally cut Vertebrae 8						X	
Distal Fibula						X	

0 – not burned (cream/tan)
1 – slightly burned; localized and < half carbonized
2 – lightly burned; > half carbonized
3 – fully carbonized (completely black)
4 – localized < half calcined (more black than white)
5 - > half calcined (more white than black)
6 – fully calcined (completely white)

Table 9 Fire #2 – using Baby (1954)

Fragment	Completely Incinerated*	Incompletely Incinerated**	Non-Incinerated***
Astragalus 1		X	
Astragalus 2	X		
Calcaneus 1		X	
Calcaneus 2	X		
Fused Central & 4th Tarsals	X		
Distal Fibula		X	
Distal Tibia 1	X		
Distal Tibia 2		X	
Iliac Crest	X		
Ischium & Acetabulum	X		
Sacrum	X		
Vertebrae 1	X		
Vertebrae 2	X		
Sagitally cut Vertebrae 1	X		
Sagitally cut Vertebrae 2	X		
Sagitally cut Vertebrae 3	X		
Sagitally cut Vertebrae 4	X		
Sagitally cut Vertebrae 5	X		
Sagitally cut Vertebrae 6	X		
Sagitally cut Vertebrae 7	X		
Sagitally cut Vertebrae 8	X		

*Completely Incinerated – fragments range from light gray, blue-gray, to buff in color and show deep "checking," diagonal transverse fracturing and warping.
**Incompletely Incinerated – 'Smoked.' Fragments blackened in color from the incomplete combustion of organic material present in the bone. Frequently bits of charred perisosteum are found adhering to the outer surface.
***Non-incinerated – "Normal bone." Fragments not affected by heat, but do show some smoking along broken edges.

Table 10 Fire #2 – using Shipman *et al.* (1984)

Fragment	I	II	III	IV	V
Astragalus 1				X	
Astragalus 2			X		
Calcaneus 1					X
Calcaneus 2				X	
Fused Central & 4th Tarsals					X
Distal Fibula				X	
Distal Tibia 1			X		
Distal Tibia 2				X	
Iliac Crest				X	
Ischium & Acetabulum				X	
Sacrum					X
Vertebrae 1				X	
Vertebrae 2				X	
Sagitally cut Vertebrae 1					X
Sagitally cut Vertebrae 2					X
Sagitally cut Vertebrae 3					X
Sagitally cut Vertebrae 4					X
Sagitally cut Vertebrae 5					X
Sagitally cut Vertebrae 6					X
Sagitally cut Vertebrae 7					X
Sagitally cut Vertebrae 8					X

Stage I (20-285°C) – commonly neutral white, pale yellow, and yellow.
Stage II (285<525°C) – common colors reddish brown, very dark brown, neutral dark gray and reddish-yellow.
Stage III (525<645°C) – neutral black, with medium blue and some reddish-yellow appearing.
Stage IV (645<940°C) – neutral white predominates, with light blue-gray and light gray also present.
Stage V (940+°C) – neutral white with some medium gray and reddish-yellow.

Table 11 Fire #2 – using Stiner *et al.* (1995)

Fragment	**0**	**1**	**2**	**3**	**4**	**5**	**6**
Astragalus 1							X
Astragalus 2					X		
Calcaneus 1							X
Calcaneus 2					X		
Fused Central & 4th Tarsals						X	
Distal Fibula						X	
Distal Tibia 1					X		
Distal Tibia 2						X	
Iliac Crest						X	
Ischium & Acetabulum						X	
Sacrum							X
Vertebrae 1						X	
Vertebrae 2						X	
Sagitally cut Vertebrae 1							X
Sagitally cut Vertebrae 2							X
Sagitally cut Vertebrae 3							X
Sagitally cut Vertebrae 4							X
Sagitally cut Vertebrae 5							X
Sagitally cut Vertebrae 6							X
Sagitally cut Vertebrae 7							X
Sagitally cut Vertebrae 8							X

0 – not burned (cream/tan)
1 – slightly burned; localized and < half carbonized
2 – lightly burned; > half carbonized
3 – fully carbonized (completely black)
4 – localized < half calcined (more black than white)
5 - > half calcined (more white than black)
6 – fully calcined (completely white)

Table 12 Fire #3 – using Baby (1954)

Fragment	Completely Incinerated*	Incompletely Incinerated**	Non-Incinerated***
Distal Tibia 1		X	
Distal Tibia 2		X	
Fused Central & 4^{th} Tarsal		X	
Distal Fibula	X		
Tarsal Bone		X	
Scapula	X		
Astragalus 1		X	
Astragalus 2		X	
Calcaneus 1		X	
Calcaneus 2	X		
Proximal Tibia		X	

*Completely Incinerated – fragments range from light gray, blue-gray, to buff in color and show deep "checking," diagonal transverse fracturing and warping.
**Incompletely Incinerated – 'Smoked.' Fragments blackened in color from the incomplete combustion of organic material present in the bone. Frequently bits of charred perisosteum are found adhering to the outer surface.
***Non-incinerated – "Normal bone." Fragments not affected by heat, but do show some smoking along broken edges.

Table 13 Fire #3 – using Shipman *et al.* (1984)

Fragment	I	II	III	IV	V
Distal Tibia 1			X		
Distal Tibia 2			X		
Fused Central & 4th Tarsal			X		
Distal Fibula					X
Tarsal Bone					X
Scapula					X
Astragalus 1			X		
Astragalus 2			X		
Calcaneus 1				X	
Calcaneus 2				X	
Proximal Tibia			X		

Stage I (20-285°C) – commonly neutral white, pale yellow, and yellow.
Stage II (285<525°C) – common colors reddish brown, very dark brown, neutral dark gray and reddish-yellow.
Stage III (525<645°C) – neutral black, with medium blue and some reddish-yellow appearing.
Stage IV (645<940°C) – neutral white predominates, with light blue-gray and light gray also present.
Stage V (940+°C) – neutral white with some medium gray and reddish-yellow.

Table 14 Fire #3 – using Stiner *et al.* (1995)

Fragment	0	1	2	3	4	5	6
Distal Tibia 1						X	
Distal Tibia 2					X		
Fused Central & 4th Tarsal					X		
Distal Fibula							X
Tarsal Bone							X
Scapula							X
Astragalus 1						X	
Astragalus 2					X		
Calcaneus 1							X
Calcaneus 2						X	
Proximal Tibia					X		

0 – not burned (cream/tan)
1 – slightly burned; localized and < half carbonized
2 – lightly burned; > half carbonized
3 – fully carbonized (completely black)
4 – localized < half calcined (more black than white)
5 - > half calcined (more white than black)
6 – fully calcined (completely white)

Scanning Electron Microscope Observations

Fire #1 – Traditional Campfire

The types of crystals observed in this fire varied widely from circular to hexagonal and oblong to a stretched cotton appearance. The average size of the circular crystals was 0.22 $\pm$ 0.07 microns, while the hexagonal crystals averaged 0.253 $\pm$ 0.06 microns. The crystals that were oblong and almost rod-like had an average of 0.416 $\pm$ 0.29 microns. I was unable to measure those with a stretched cotton appearance because sintering obliterated individual crystals.

Fire #2 – Charcoal Lighter Fluid

The crystals observed in this fire were most clearly hexagonal in shape with an average size of 0.5545 $\pm$ 0.13 microns. On this particular region, at a magnification of 15,009 times and a working distance of 10.8 mm, there appears to be smaller crystals attached to the larger hexagonal crystals though when magnification was adjusted to 14,981 times and a working distance of 10.77 mm the specks disappeared.

Fire #3 – Gasoline

The crystals in this fire were significantly larger than those of Fire #1 and/or Fire #2. The crystals from this fire are more globular with smaller individual crystal attached to the surface. The average size of the large globules is 1.616 $\pm$ 0.89 microns, while the smaller ones attached to the surface had an average size of 0.1444 $\pm$ 0.08 microns. The structure of these globules gives the appearance of being "fuzzy or fleecy" appearance as described by Shipman *et al.* (1984).

Figure 4 – Fire #1 – SEM

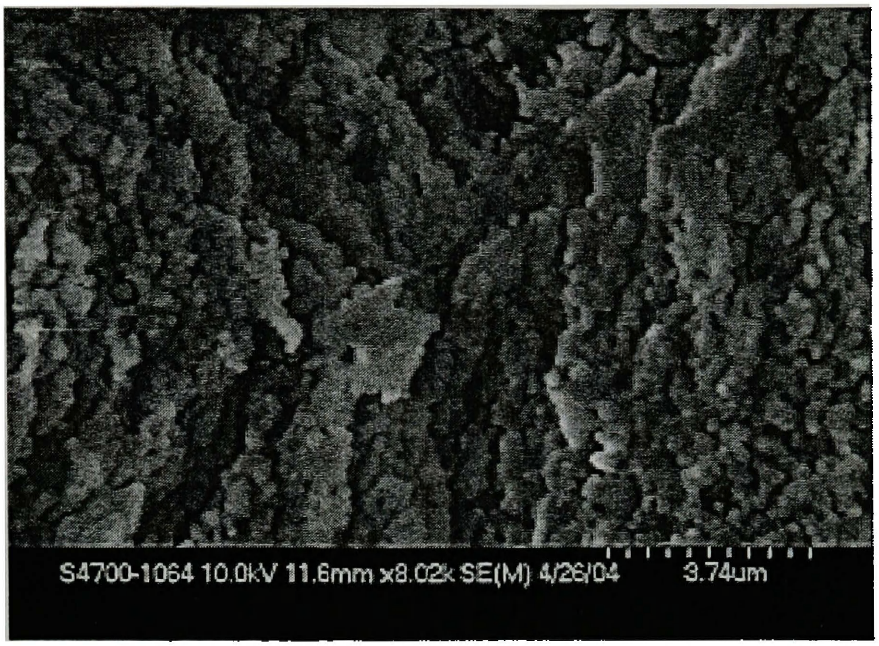


Figure 5 – Fire #2 - SEM

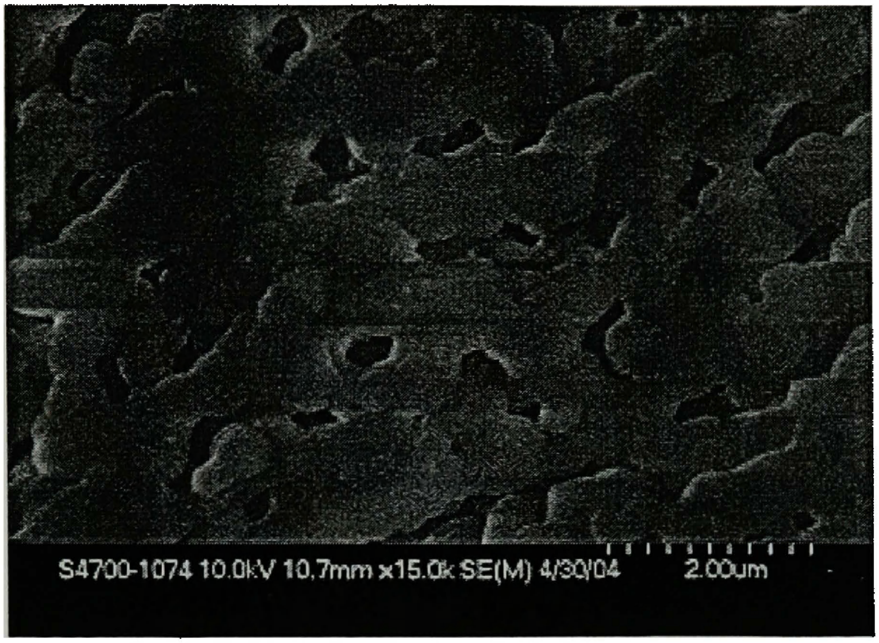
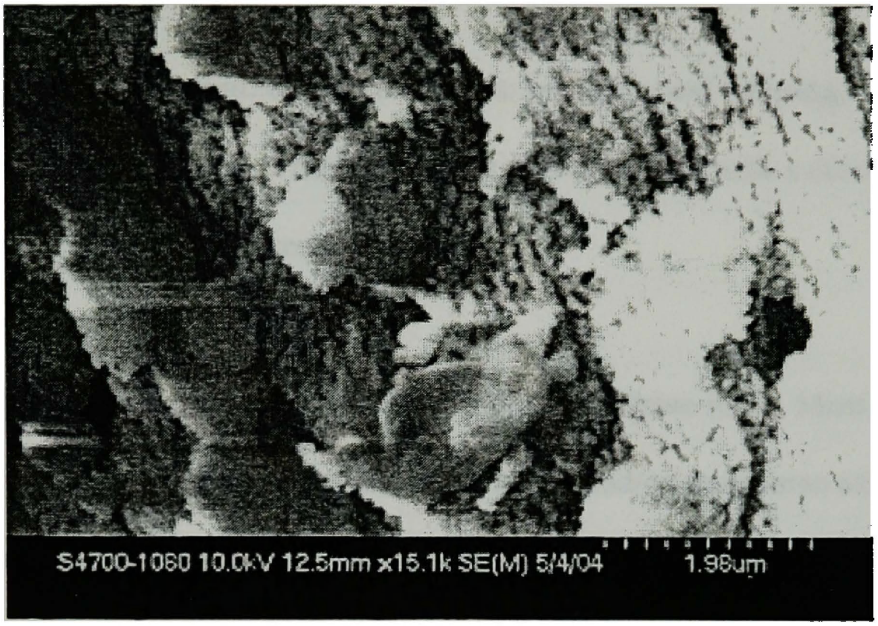


Figure 6 – Fire #3 – SEM



Chapter 6: Discussion

The discussion section is organized into five parts: breaking and warping, fire temperature, recovery and SEM results. The last chapter will conclude with a discussion of the possible sources of experimental error.

Breaking and Warping

The pattern of breaking and warping was consistent in all three fires. Most if not all of the bones were cracked or broken along the longitudinal and/or transverse axis. Curved cracks were observed along all of the epiphyses. The only noticeable warping was on the ribs. These observations are consistent with the findings of Eckert *et al.* (1988), Baby (1954), Binford (1963) and Thurman and Willmore (1980-81). There were no obvious differences between the fires, meaning that the different accelerants or lack of had no effect on the bones with regard to breaking and warping.

Fire Temperature

All of the fires reached at least 600°C for about 30 minutes or more. The two fires that were started with accelerants should have burned much hotter than the one without an accelerant.

Fire #1 (no accelerant) stayed above 600°C for about 30 minutes before the temperature began to drop off rapidly. This disagrees with the statement made in the study by Tylecote (1962; cited in Shipman *et al.*, 1984: 308) that traditional campfires reach a temperature of about 400°C and rarely reach 700°C.

Fire #2 (charcoal lighter fluid) almost instantly reached a temperature of 600°C or above and maintained that high temperature for approximately 25 minutes before dropping off and stabilizing to a temperature of 300-400°C.

Fire #3 stayed above a temperature of 600°C for 45 minutes, longer than either of the other fires. The longevity and intensity of this fire would be expected because of the use of gasoline.

Based on the measurements taken and the temperatures reached by each fire, there was not a significant difference between the fires with accelerant and the one without. There is no doubt that the fires reached a temperature higher than 600°C, but just how high is an unknown. To see how the bones were affected by each fire and if either accelerant had any effect on the bones, the recovery of the bones must be looked at.

Recovery

It was expected that the fire that burned the hottest, longest would yield the least amount of material recovered and that material would be the most completely incinerated. The results of the experiment showed, at least macroscopically, that this was not the case.

Fire #1 and Fire #2 both stayed above and beyond 600°C for about a 30 minutes. Using the standards set by Baby (1954) approximately 77% of the bones of Fire #1 and 81% of the bones of Fire #2 were determined to be completely incinerated. Fire #3, on the other hand, stayed above 600°C for about 45 minutes. Again, using Baby's (1954) standards, only 27% of the bones in Fire #3 qualified as being completely incinerated. This is exactly opposite of what should have happened considering burning time and temperature. When only the bones that all the fires had in common were used, the differences between the fires in percent of bones completely incinerated becomes even more dramatic: Fire #1, 100%; Fire #2, 50%; Fire #3, 25%. The same pattern is repeated when all bones in common are applied to both Shipman *et al.* (1984) and Stiner *et al.*

(1995) standards although the differences are not as dramatic. The bones of Fire #3 are consistently less burned than those of the other two fires.

All of the fires were built roughly to the same size and shape. The only difference between them was that Fire #1 was allowed to burn and get coals before the bones were put in. This may explain why the bones of Fire #1 were consistently more incinerated than the other two but it does not explain the significant difference between Fire #2 and Fire #3. The different positions of the bones in the fire is the only possible explanation that can be offered for this discrepancy.

SEM Analysis

There are significant differences in the size and shape of crystals observed in bones in each type of fire. Fire #1 had the most variation in types of crystal present (spherical, hexagonal, oblong and a stretch cotton appearance). Fire #2 exhibited only hexagonal shaped crystals while Fire #3 contained large globules with smaller crystals attached to the surface, as well as some sintering.

Though the macroscopic observations of whether or not a bone was completely incinerated by the temperature of the fire had varying results, SEM analysis confirmed what should have been expected from each of these three fires. Crystals only begin to change at very high temperatures. Spherical crystals are observed in the 600°C range up to about 800°C to 1000°C (Holden, 1995b: 34). When the temperature reaches this 800-1000°C range, the crystals begin to take on a more hexagonal morphology (as seen in Fire #2). This 800-1000°C range is also important because it is also at these high temperatures the crystals begin to exhibit distinctive enlarged mineral structures, such as large globules (Nicholson, 1993: 421). The temperature at which crystals begin to sinter varies among researchers; Shipman *et al.* (1984: 321) observed sintering at around 800°C while Holden *et al.* (1995b: 34) observed it as around 1000°C. Based on this information it can be affirmed that the fires reached a much higher temperature than was recorded and agrees with the original idea that there would be a difference between the bones of each fire.

Sources of Error

There were several possible sources of error with this experiment. The first is that a more accurate measure of temperature would have been desirable. The temperature was difficult to measure because of the experimental nature of the fires. The use of a Thermal Imaging Camera was the best device that was available, accurate and cost effective.

Another potential source of error lies in the methods used. Perhaps Fire #1 should not have been started before the bones were placed in it. This was done because if one were trying to dispose of a body, one would likely start the fire first if they were not using any type of accelerant to make sure that the fire was burning well before a body was placed in it.

Finally, it would have been beneficial to have used Gas Chromatography (GC) or Gas Chromatography / Mass Spectrometry (GC/MS) to test for the presence of accelerants. However, a GC/MS was not available for my use.

Chapter 7: Conclusion

My original hypothesis was that the fires that contain accelerants should burn hotter and therefore should have a greater effect both macroscopically and microscopically on bones than that of a traditional campfire. I am not able to fully reject the null hypothesis, which states that there is no difference macroscopically or microscopically between fires burned using an accelerant and those burned without.

I can state that macroscopically that there was little to no difference between the bones burned in the fires. Microscopically, however, there were definite differences although I am not able to say with certainty that these differences are a direct result of the accelerants. The microscopic results were more likely a result of hotter fire caused by the use of accelerants. It was impossible to visually differentiate bones burned by the fire that used charcoal lighter fluid from those exposed to gasoline, though again, there were microscopic differences. The use of GC/MS may be able to provide additional data to clarify this.

The aim of this project was to see if there was a fairly easy way to detect whether a body had been burned accidentally or had deliberately been set on fire in an outdoor setting. If it was found that there was a simple way to tell the difference, it would help police, fire investigators and well as forensic anthropologists be able to determine whether a crime had been committed or if the situation was simply an accident.

The determination as to whether a bone has been burned or not is still a question among archaeologists and anthropologists alike. Although macroscopically, many events can make a bone look like it has been burned, it seems that by using a SEM, one should be able to answer this question more easily, even though some research indicates that effects of weathering may overlap with those of burning.

There is no doubt that more research needs to be done regarding burned remains. Finding some reliable way of macroscopically determining whether a bone is burned would answer anthropological questions of cannibalism--when people first began to cook with fire, as well as add to the knowledge of cremation studies. All we can do is keep trying to find new ways in which fire affects bone, more specifically, the way fire affects histological features of bone since we obviously cannot rely on macroscopic features.

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