Bone Breakage and the Taphonomy of Cooking: An Actualistic Study

Graham Callaway

College of William and Mary

Follow this and additional works at: https://scholarworks.wm.edu/honorstheses

Recommended Citation
https://scholarworks.wm.edu/honorstheses/801

This Honors Thesis is brought to you for free and open access by the Theses, Dissertations, & Master Projects at W&M ScholarWorks. It has been accepted for inclusion in Undergraduate Honors Theses by an authorized administrator of W&M ScholarWorks. For more information, please contact scholarworks@wm.edu.
Bone Breakage and the Taphonomy of Cooking: An Actualistic Study

A thesis submitted in partial fulfillment of the requirement for the degree of Bachelor of Arts in Anthropology from The College of William and Mary

by

Graham Alan Callaway

Accepted for High Honors (Honors, High Honors, Highest Honors)

Martin Gallivan, Director

Joanne Bowen

Lorena Walsh

Williamsburg, VA
April 24, 2008
Introduction

In any culture, what foods are eaten, who eats them, how they are prepared, and the symbolic meaning attached to these actions is fundamentally linked with how that culture interacts with the world. Eating is a human necessity and therefore is constant across cultural boundaries, but it can also serve a myriad of other roles for different cultural groups. Foods can serve as a luxury item to reinforce social divisions, as a social homogenizer across a group whose members eat similar diets, as a focus for ritual activities, as a link to tradition, and in any number of other socially charged ways. Clearly, the study of which foods are consumed in a culture, by whom they are consumed, and after what preparation can be of critical usefulness in understanding that society’s perception of itself, its social structure, and the natural world. Furthermore, methods of food preparation and consumption can be communicated to other groups with which a society interacts, and recognition of this exchange can aid in the study of interactions between cultures.

In order to address such questions archaeologically, it is necessary to study the relationship between those food remains which are frequently recovered in the archaeological record and the various taphonomic processes that act upon them. This study was originally conceived as an experimental investigation of the relationship between different methods of cooking and various aspects of breakage in mammal bone, and considers the question of whether it is possible to identify cooking techniques based on taphonomic attributes. Numerous medium- to large-sized mammal limb bones were acquired, and groups of them underwent various cooking techniques before all were
broken in a similar fashion. During this process I controlled as many variables as was logistically feasible. The most salient data about each break was subsequently collected, and an attempt was made to correlate patterns across the bones under study with cooking method, or with other variables that could not be controlled. Data was investigated using simple qualitative assessment, then with the aid of simple graphical analysis, and finally using more complex multivariate statistical modeling, all with the aim of characterizing the observed trends in meaningful ways. As is discussed below, the connection between breakage patterns and cooking method are not as clear as might be hoped, though some relationship appears to exist. The unclear nature of the relationship appears to be largely the result of the “noisiness” of the data set under investigation and particularly, it is believed, the result of the freezing of most bones in the study. A variety of other factors which influence breakage pattern are also addressed, with the ultimate conclusion being reached that bone breakage is an immensely complicated process influenced by a huge number of factors, of which cooking is one. This suggests that the interpretation of cooking from archaeological breakage patterns might be possible, but the large number of factors which would have to be controlled would make it immensely challenging. The results of this study speak to the value, as well as the limitations, of experimental archaeology in contributing to the greater archaeological discourse and in helping investigators to understand the various processes that might have influenced material they recover.

Theoretical Groundwork

As is presented at length by Lyman (1994), archaeologists rarely studied or
discussed taphonomic processes prior to the late 1970s. This early work concerned itself largely with understanding the processes by which an assemblage was accumulated and differentiating between assemblages that reflected human transport and processing of material, carnivore processing, water transport, and so on (see Gifford 1981 for an excellent review of this work). Zooarchaeologists in comparatively recent times have become more interested in understanding the history of bones on a more individual level and thereby attributing bone modification of various types to specific formation processes. The focus of many researchers working with this type of question has been the identification of butchery marks caused by humans and distinguishing them from, for example, marks caused by carnivore teeth. This has resulted in numerous experimental studies of taphonomic processes, spearheaded by the work of Pat Shipman (e.g., Shipman 1981, Potts and Shipman 1981, Shipman and Rose 1983) whose greatest focus was the attempt to differentiate between human cutmarks and naturally occurring modification through the examination of both on a microscopic scale. Shipman’s work has been criticized by numerous scholars for its readiness to ascribe marks on bone to specific processes when other processes can cause very similar marks, essentially a problem of insufficient control in experimental studies (e.g., Behrensmeyer et al. 1986, Haynes 1991, pages 158-163). This problem continues to plague actualistic research in archaeology.

The zooarchaeological study of food has not always been concerned with taphonomic processes. Rather, such work has traditionally been more focused on such evidence as human transport of meat from butchery camps to home sites, the relative dietary importance of the species represented, butchery practices, seasonality of dietary
importance of different taxa (e.g., Gifford 1981, Cleland 1970, Bunn 1989, and Mellars and Wilkinson 1980 respectively), and more recently topics such as cultural identity and social position of the consumers and a concern with food as cuisine or a luxury item (e.g., Grantham 2000, Emery 2003, van der Veen 2003). However, even these more recent studies tend to focus on the elements represented and locations of butchery marks in making their interpretations. This is not surprising, as such patterning is among the most salient and best-studied aspects of zooarchaeological assemblages, but this approach neglects the possibility of addressing more subtle taphonomic processes that act upon bone and that may be able to provide valuable insight into the history of an assemblage.

One line of questioning inspired by the concern with the taphonomic history of individual bones and the nature of assemblages based upon patterning across them has been the study of cooking. Not all cooking methods affect bone in the same way. That bone can be softened considerably by boiling is common knowledge, as is the fact that dry roasting has a different influence. The idea that bones which have undergone these processes would behave differently when broken is an intuitive one. Thus, it is natural to assume that different methods of preparing meat will leave somewhat different traces archaeologically, particularly wet as opposed to dry cooking methods (boiling as opposed to roasting), especially if the bones were broken after their preparation so that the influence of processes such as cooking which might be reflected in the breakage pattern can be observed.

However, there have been remarkably few systematic middle-range studies of this topic, a fact noted by Gifford-Gonzalez (1993), and those few that have been undertaken
have generally used sample sizes too small to be statistically viable (e.g., Roberts et al. 2002, Pearce and Luff 1994). However, these studies did provide some indication that distinguishing these different categories archaeologically might be possible. One contrasting result comes from Alhaique (1997), whose comparison between roasted and uncooked sheep bones indicated that, while there did seem to be some relationship between cooking and breakage, other factors have a sufficiently strong obscuring influence that reliable differentiation is impossible. Other studies have attempted to interpret cooking using data other than breakage, such as charring and element frequencies (e.g., Speth 2004).

Due to the lack of substantial work on the topic, researchers currently are not able to reliably differentiate between uncooked bones and cooked ones, much less interpret cooking methods. Naturally, the life of a bone as food can be and often is more complicated than simply being cooked and discarded. For example, Crader has suggested that bones found on a slave site with cut marks indicating carving as a roast may have been refuse from the mansion house, re-used in a stew (1990). Even if patterns linking cooking method with breakage could be observed, the ability to differentiate to a finer degree would also be necessary for questions of cultural identity and cuisine to be confidently addressed.

The purpose of this study has been to work toward filling the gap in this aspect of taphonomic research by demonstrating a connection between cooking method and physical characteristics of breakage. Successful demonstration of such distinctive characteristics would suggest one or more follow-up studies in which butchery
techniques and common recipes of a specific time period and geographical area would be replicated on the bones under study in order to create a reference database/comparative collection, which could be used by researchers working with material from that period. Success in this endeavor would allow archaeological faunal material to be characterized in terms of cooking method, which would be of tremendous aid in answering a wide variety of questions relating to foodways and cuisine.

As an example of a question this type of systematic, statistically viable middle-range study could cast significant light on, it has long been recognized in early colonial sites that faunal assemblages representing the refuse of enslaved Africans are more highly fragmented than those of their masters from the same sites (the statistical significance of this distinction is borne out in Lattimore 2002, unpublished). The standard interpretation of this fact is that enslaved Africans frequently prepared their meals by boiling them for extended periods, making so-called “one-pot meals” that would have been less labor intensive and more nutritious than other methods (Otto 1984). This has also been interpreted by some researchers as representing a link to the slaves’ West African roots, where stewed foods were common, the cooking style perpetuated as a means of preserving cultural identity and easing transition (e.g., Samford 1996). Lattimore has called these interpretations into question (2002 unpublished), showing that numerous other factors may account for the greater fragmentation and that it is not necessarily due to lengthy boiling. The potential for actualistic research to speak to such a question is clear.
Methods

The ideal sample for a study such as this would be a group of skeletal elements that were as uniform as possible, in order to facilitate comparison between samples and reduce the number of variables that could impact breakage patterns. Ideally, this would mean that the same element from the same species would be used throughout, with *Bos taurus* being the initial choice, because a number of such limbs were already available to the project. In practice, particularly because the vast majority of material used was donated and a fairly large sample size was desired, this was not possible, but the attempt has still been made to maintain the highest feasible degree of uniformity throughout the sample. All bones used were limb bones from medium- to large-sized mammals, including *Bos taurus*, *Sus scrofa*, *Ovis aries*, and *Odocoileus virginianus*, and the attempt was made to ensure that no taxon was drastically underrepresented. A variety of cooking techniques were investigated, with the largest sample sizes being uncooked, boiled, and roasted, though there were minor representation of other techniques, such as salted/smoked and roasted-then-boiled.

It has been shown by other researchers that bone cooked while still insulated from the heat by the meaty tissue surrounding it behaves differently from bone cooked without this cushioning effect. Indeed, “a study by Alhaique (1997) showed that temperatures did not exceed 85° C around the bone at an oven temperature of 200° C, and in most cases were much lower” when the meat was cooked by dry heat such as roasting (Roberts et al. 2002). This necessitated the acquisition of bones cooked with the meat in place, particularly for testing the effects of dry cooking methods. Most such material was
Callaway 8

donated by the Colonial Williamsburg Foundation Department of Historic Foodways staff and was cooked by them prior to its acquisition for this study. The other material was donated by a variety of sources, with the majority coming from Joanne Bowen, Colonial Williamsburg Foundation Department of Archaeological Research.

Because much of the cooked material underwent reproduced colonial cooking techniques, it was deemed valuable to research and understand these methods based on a number of primary texts. These are listed in their entirety in a separate section of the Works Cited, but the most important were Glasse 1796, Lea 1853, and May 1678. These texts allowed the cooked material to be correctly organized according to cooking method, as the categories used for analysis were based on modern methods rather than colonial ones.

One other factor of interest to this project is the influence of freezing on bones. To date, this has been almost totally un researched by archaeologists, being addressed only briefly by Carlee as it relates to pest management in a museum setting (2003). Financial and logistical constraints necessitated the freezing of most bones in this study, most for a relatively short period, although some of the *Bos taurus* used had been frozen for over ten years (the so-called “Freeze Dried” category). A small number of bones were acquired that had never been frozen prior to being chopped. As acquiring unfrozen bones is an obvious logistical challenge, only one taxon, *Sus scrofa*, is represented within this group, and it is of an unfortunately small size. However, subsequent analysis of this material in contrast with that which had been frozen demonstrates the importance of the influence of freezing on bone breakage, as will be discussed.
Material was chopped on a wooden chopping block, using a heavy axe. Each bone was photographed before and after being chopped, and a variety of notes were taken on each cut. All bones and fragments were stored in plastic bags and were frozen after being chopped. Material was subsequently thawed and boiled (in mesh bags to prevent loss of bone chips) in order to dislodge any remaining meat, and was subsequently cleaned by hand. Bones were then soaked for several weeks in a solution of 25 – 50% ammonia in water in order to break down remaining proteins, with the solution being changed periodically. This process allowed the cleaned bones to be investigated and measured easily, and also allowed them to be curated for possible future study.

Each bone and cut are designated by a number, such that 1-1 is the first cut on the first bone, 2-1 is the second cut on the first bone, 1-2 is the first cut on the second bone, and so forth. The order in which bones were broken was essentially random, and approximates the order of their acquisition. The majority of bones were cut only once, as it was determined that the presence of previous cuts on a bone had a strong influence on the direction of a break, particularly the direction of cracking. A number of self-evident facts about each sample were recorded as well, such as cooking method, whether or not it had been frozen, taxon, element, previous cuts on the bone, and so on.

A variety of data were then collected from each bone after cleaning in order to characterize its breakage, including the number, size, and weight of fragments, a series of observations for characterizing cracking, whether or not cancellous bone was present at the point of impact, and the size of the three major portions of the break in each case: the strike platform, representing the entry of the cutting tool itself, break depth (called
“sawtooth ridges” in Uschner 1996, unpublished), and shatter, that portion that extends from the end of the break depth through the rest of the bone (Figure 1). Shatter was not always present – in some cases the break depth extended through the entire bone beneath the strike platform. A spreadsheet that includes all data used in this project will be attached to this document and is also available online at http://gacall.people.wm.edu/.

The quantification of breakage in this manner should be briefly justified. Methods for doing this have been and continue to be a subject of controversy among zooarchaeologists, with various researchers espousing different methods for describing and measuring fractures. Many recommended that bones be categorized into a number of
“fracture types” (e.g., Shipman et al. 1981, Marshall 1989, Johnson 1985) but, as Lyman points out, these categories are largely subjective and ultimately difficult to use (1994, 320). Others have devised more quantitative systems that help to reduce bias and enable data to be more easily computerized (e.g., Biddick and Tomenchuk 1975, Abe et al. 2002). While I have a great deal of respect for such methods, they are geared towards accurately determining the MNI count for an assemblage, not assessing the impact of taphonomic processes. I chose instead to quantify relatively salient aspects of breakage, as the purpose of the study was to identify and discuss broadly observable trends in bone breakage. The only measurements I took that were somewhat unusual were of the components of each break (strike platform, break depth, and shatter). These were inspired by Ushner (1996, unpublished), though they can also be thought of as a simplification of the “features of fracture surfaces” described by Lyman (1994, 326-328). They are somewhat unorthodox as quantified breakage data, and simply reflect my attempt to record this information in the simplest possible way.

Information was gleaned from the results of this study in three different ways. The initial strategy was to perform statistical analysis in order to create a model characterizing the data that would be able to correctly predict cooking method based on other variables. As this was not entirely successful, a variety of graphical representations of the data were created for simple characterization of it in visual terms, useful for understanding general trends and basic patterning across the data set. Finally, a number of observations can be made simply based on the experience of working with the bones and observing certain tendencies in them. Such observations were first made while the experiment was
Statistical interpretation of the data was performed in partnership with Matthew Hanson and used two broadly defined techniques: hypothesis testing and forecasting. Hypothesis testing describes a variety of techniques that are used to determine the significance of variables. Insignificant variables are dropped from the model whenever possible, and the more this can be done, the smaller the confidence intervals on the remaining variables are. Reducing the number of variables can also include the merger of variables into broader categories, such as the reduction of fragmentation data from ten categories (five size groups and weights for each) to three (total number, total weight, and average weight per fragment). The specific method used for hypothesis testing was the multinomial logit estimator. This procedure is widely used by statisticians for hypothesis testing when the dependent variable takes on categorical values. The multinomial logit estimator is a maximum likelihood procedure that estimates the effect a particular variable has on the likelihood of each categorical outcome – for example, a value of one instead of zero in a variable may increase the likelihood by 5% that the bone was boiled, while reducing by 3% the likelihood that the bone was uncooked. The multinomial logit model assumes a logistic distribution for the noise, or error term, in the data. More details on the multinomial logit estimator can be found in Greene (1993, pp. 666-668). Unfortunately, this study includes a very high number of variables, and very few could actually be removed, meaning that the confidence intervals for all the remaining variables
are large, leading to an inability to meaningfully test statistical significance of any one. Essentially, no variable appears to be individually significant, but this could just as easily be the result of the high number of variables in the model as it could be the result of the actual insignificance of any of them. The test of all variables together indicates a high level of significance, but this is not helpful for determining which individual ones are significant.

The results of forecasting are more interesting. Forecasting refers to a range of techniques whereby the data are used to construct a model which makes predictions about data points. For the forecasting in this study, we estimated a multinomial logit model, and then selected the cooking method with the highest estimated likelihood from the model as our estimate of the cooking method. Specifically, we attempted to predict the cooking method used on each bone by constructing a model for it using all other bones, and to do this for every bone under study. This technique does not differentiate between cooked and uncooked bones with appreciably more success than random chance, but it correctly identifies cooking methods about half of the time, considerably better than random chance.

These results support the notion that breakage and cooking method are related on some level, though the relationship is not strongly predictive. The model is relatively successful at distinguishing between cooking methods, but if bones cannot be reliably characterized as either cooked or uncooked to begin with, this fact is of interest but not terribly useful. A model was also constructed using all cooked bones as a large group and attempting to differentiate between them and the uncooked group, but this model was not
appreciably more successful in identifying uncooked specimens. Regardless, this weak patterning across the cooked bones does certainly seem to indicate that there is some relationship at work, but that the available data was not able to characterize it in a predictive fashion. Any number of explanations might exist for this, the most probable being simply that the data set is too noisy. The variability in the taxa and elements under study alone could be immensely obscuring, although Alhaique demonstrated a similar phenomenon of visible but not predictive patterning with a sample composed entirely of sheep hindshanks (1997).

Graphical Interpretation

Graphical representations of the data were made of many of its aspects in order to observe patterns, the most interesting examples being cracking data, fragmentation data, and data on the components of the breaks themselves. These were interpreted with reference to cooking method and taxon, though other variables were also investigated over the course of the analysis. Investigation of this type allows those factors believed to be most interesting to be specifically targeted for observation, as well as for patterns in the data to be more easily noticed.

Figure 2 is a histogram representing the maximum lateral distance of cracking, which refers simply to the furthest distance along the bone reached by cracks from the point of impact, divided according to taxon. From this graph alone, it should be clear that *Bos taurus* represents a highly varied group (something it also manifests across other variables), due no doubt in part to the “freeze-drying” of many of the samples. It was subsequently deemed valuable to remove *Bos taurus* from these figures and to simply
Figure 2

Maximum Lateral Distance of Cracking

[Taxon] Sus scrofa

[Taxon] Ovis aries

[Taxon] Odocoilus virginianus

[Taxon] Bos taurus
compare the smaller taxa with one another. As a result, these samples are excluded from subsequent graphs, and are retained in Figure 2 only to demonstrate this point.

Figure 3 is a necessarily complicated graph, but an interpretively important one. It is a representation of fragmentation counts for each sample, divided into size categories and labeled by cooking method. The most important point gleaned from Figures 2 and 3 is that *Sus scrofa* appear to trend low in both fragmentation (number and size) and cracking. As Figure 3 shows, this is particularly true of those samples that were never frozen, the only samples of this type in the entire study. Those samples of *Sus scrofa* that had been frozen seem to display more random variation in fragmentation than their never-frozen counterparts, though still trending low, and to manifest higher cracking, as Figure 4, a histogram comparing cracking in frozen and unfrozen *Sus scrofa*, demonstrates (contrast also Figure 5, a never-frozen *Sus scrofa* and Figure 6, a frozen and thawed *Ovis aries*). This suggests that freezing has a randomizing effect, such that the general trends of breakage, which appear to be influenced by a variety of factors – including taxon, element, and cooking method, to name a few – are still present, but with considerably more variation of an apparently random nature. This helps to explain the apparent randomness that is manifested across other taxa in the study, unrelated to any other variable investigated, most strikingly among *Odocoileus virginianus*, otherwise a very homogeneous group. Attempting to read through the noise, it appears in Figures 2 and 3 that *Odocoileus virginianus* trends toward higher fragmentation and cracking, while *Ovis aries* trends toward lower fragmentation but higher cracking. It is also possible that freezing results directly in a tendency for higher cracking, though if this is the case the
Figure 4

Maximum Lateral Distance of Cracking, Sus scrofa Only
high variation across *Ovis aries* and *Odocoilus virginianus* is more difficult to explain. Regardless, these trends in fragmentation and cracking appear to hold across cooking methods and elements in at least a general way, though the noise that I believe to be the result of freezing makes them difficult to assess confidently. It is, of course, possible that some factor other than freezing is at fault here, but that is where the limited data provided by this study point. Future experiments could easily be constructed to investigate this trend.

By contrast with the preceding discussion of cracking and fragmentation, examination of the relationship between the components of a break (which I refer to as “strike platform,” “break depth,” and “shatter,” see Figure 1) has been less enlightening. In order to mitigate the influence of bone size on the relationship between the sizes of these features, they were examined as percentages of the sum of the three rather than as simple totals (Figure 7). A missing column reflects a case that did not display these features, usually because the cut was made at the end of a bone rather than its shaft. All bones appear to manifest an essentially random distribution when compared in this way, and no correlation is apparent with any other variable investigated.

This lack of patterning observed in break components with respect to freezing, when this variable manifested much stronger correlations with fragmentation and cracking, is itself suggestive. This pattern indicates that, although freezing does have an appreciable influence on bone breakage, there are aspects of it that are not as strongly affected. I am not prepared to offer an explanation for the visibility of a correlation of this variable with some aspects of breakage but not others, and recognize that such a
trend might exist for these breakage components as well if a sufficiently large sample was investigated. Even if this is so, it is clear that fragmentation and cracking are both much more obviously affected. Thus, though I do not suggest that any study should entirely discount the potential influence of freezing, it seems that certain types of investigation must be more concerned with the issue than others.

Other Observations

One conclusion which, on a very basic level, was clear independent of any numeric analysis is that the influence of freezing on breakage can be quite profound. In the “Freeze Dried” category – those bones that had been in storage for over ten years – many of the bones demonstrated extremely unusual breakage of a type that resembles practically no archaeologically recovered bones (Figure 8). These samples were also notably dense and dry, and many of them released a large amount of unrecoverable bone dust when chopped. No other groups exhibited these traits, including those which had been frozen for a shorter period (no more than a month or two), though the more subtle influence of this shorter freezing has already been addressed. While this observation is not very archaeologically interesting, it does provide a strong indication that experimental studies of this type should make every effort to limit the duration during which material under study is frozen prior to being worked with, and preferably avoid freezing entirely. Very old material, like these “freeze dried” bones, is best used as part of a comparative collection or in some similar context in which its physical and chemical properties are not critical.
One other interesting observation can be made based simply on the experience of working with the material – that of the role of existing cuts, sometimes little more than scratches, in determining the way in which a bone will break. The existing cut can be quite distant from the point of impact of the new break, but in most cases in which a previous cut exists, there is nevertheless a very pronounced trend for the bone to crack in the direction of the existing cut, whether or not it successfully propagates itself this far. In some cases this trend could be seen to exert a distinct influence on the breakage pattern observed (Figure 9). While not noted elsewhere in the literature in this context, this trend is quite intuitive and readily explained by the structure of mammal bone as a material.
As is well-explained by McGowan (1999), the compact, or lamellar bone in mammals is made up of a series of structures called osteons. An osteon is made up of a central tube called a Haversian canal, which in life contains capillaries and nerves. The Haversian canal is surrounded by several layers of lamellar bone (lamellae), which in turn are surrounded by a cement layer the composition of which is not well understood. These osteons run generally parallel to the long axis of a bone. The lamellar bone itself is a composite material, made up of fibers of collagen, an elastic protein, in a matrix of calcium hydroxyapatite. The collagen fibers are either oriented longitudinally, parallel to
the long axis of the osteon, or spiraled so as to lie at predominantly right angles to it, depending upon the direction of stress regularly experienced by the bone in life. This causes a bone's strength to be considerably greater in the direction of the stresses it normally experiences, at the expense of its strength in other directions. See McGowan 1999 for an excellent and more detailed discussion of bone structure and breaking.

Bearing the structure of bone in mind, the role of previous cuts in breakage is readily explained. The directional nature of bone as a material results in the transmission of the energy of an impact more readily along osteons than across them. A cut in a bone represents the severing of these directional channels, trapping the energy of impacts. This causes the greater propagation of cracks parallel to the long axis of osteons in the direction of extant cuts in the bone, resulting in a greater tendency for such bones to display fractures that “lean” towards previous cuts. Awareness of this trend could be important for the interpretation of some types of bone breakage.

**Interpretation**

First, in terms of addressing the project's initial goals, the influence of the various cooking methods on the bones under study was not as clear as had been hoped. There are no obvious, reliable trends in breakage resulting from cooking to be found. However, results do suggest that there is some patterning to the data, and that additional research might allow archaeologically recovered bone to be characterized according to cooking method with some level of confidence, provided sufficient research was done. However, for the time being, such identification according to breakage information is impossible.

On that note, it is worth underscoring the importance of a cultural awareness
when undertaking zooarcheological analysis, as knowledge of practices that might contribute to fragmentation and other aspects of an assemblage's formation within a given culture can help direct interpretations and correctly attribute observed patterns. This was made clear by the documentary research associated with this project. Specifically, cuts of meat tend to undergo various cooking practices based on the part of the animal from which they are taken. For example, recipes for preparing the tough meat from the lower legs of most domestic mammals will almost inevitably involve boiling or stewing, at least in the European tradition. Of course, the fact that recipes were set down in this way in cookbooks does not necessarily mean that the pattern will hold in practice, but knowledge of common cookery practices regarding different cuts of meat for any given culture under study could itself provide a valuable interpretive tool for the archaeologist. Speth has also demonstrated that it is sometimes possible to identify differences in cooking techniques based upon element frequencies for different taxa (2000). Similarly, Lupo and Schmitt have demonstrated that highly fragmented mammal bones may reflect grease-rendering activities, and that the chopping of bones to a uniform “pot-size” may be indicative of boiling (1997).

Aspects of the results of this project are interpretively interesting in other ways, first and foremost the observations on the effect of freezing. Given the apparent influence of freezing on breakage, the question that follows is of the nature of this influence. Is this randomizing effect the result of incomplete thawing of the water held in the bone, such that it is still partly frozen at the time of breakage, or does freezing engender a more permanent change in the physical or chemical structure of bones,
changing their normal physical properties? Various groups of bones in this project were thawed for different lengths of time before being cut, a factor not recorded as part of the main data table because it was not precisely measured, but in no case was it shorter than twelve hours. More noteworthy, however, is the fact that the group of previously frozen bones boiled on 9/19/07 were not refrozen between this cooking event and their chopping, fully two days later. This rules out the possibility that this material was at all frozen, and strongly suggests that freezing results in a more permanent change in the breakage patterns of bones. Further support for this idea lies in the tendency already discussed for bones that had been in storage for long periods to be qualitatively very different from others, seeming much drier and denser. This “freeze-dried” state seems to be the final stage of a process of physical or chemical alteration induced in bones by freezing, which I can only conclude also acts in meaningful ways on bones frozen for comparatively short periods.

Though this is not a process in which the archaeological community has previously taken an appreciable interest, other fields have addressed the issue to an extent. For example, in medicine, bones and other tissues are frequently frozen prior to their use as transplants, and the influence of freezing on these tissues has been studied to some degree, for example by Voggenreiter (Voggenreiter et al. 1994), with that study concluding that freezing “had no deleterious effects on the surface structure,” though freezedrying (in this case the actual removal of water from frozen material in a vacuum) resulted in the formation of numerous microcracks. Though not specifically addressing bones, a similar issue has been addressed in a wildlife management context as regards
frozen meat, with the aim of developing a process by which meat could be identified as either fresh or frozen-and-thawed, thus improving the prosecution of out-of-season hunting (McCormick et al. 1990). These authors describe a number of physical and chemical changes that occur when meat is frozen and subsequently thawed, many of which are also affected by aging of the meat, but which are not directly applicable to investigation of bones. However, this does suggest that analogous processes occur in bone tissue. Other scholars (e.g., Farrant et al. 1977) have demonstrated that the conditions under which animal tissue is frozen and thawed, particularly the rate of freezing and thawing, can have a significant influence on the ability of that tissue to survive the process, another issue which should be investigated in the context of experimental zooarchaeology. It is also worthwhile to note at this point that the influences of cold storage and aging on bones are also totally unresearched. Study of any of these topics would have the potential to drastically improve the experimental methods of later studies, and they would be comparatively simple projects to execute.

Of course, there are a number of other factors that may also influence the apparent randomness within the study sample but could not be controlled for, most importantly such factors as the age at death, health, and diet of the animals. However, such factors cannot explain all variation, as in many cases bones that were articulated with one another behaved quite differently when chopped. Nevertheless, it is likely that the inability to account for such factors as these further obscures the general trends already noted above. Controlling such factors might help mitigate the randomness ascribed here to the influence of freezing. Additionally, studies such as this one do not generally
address the skill of the person wielding the tool as a possible factor in breakage. The ability to strike consistently and accurately is not a skill that comes without practice, and it is likely that the data for similar studies might suffer as a result of this issue. In the case of this project, the primary investigator's long history in the use of an axe somewhat mitigates this concern, though the potential for it to have had an influence must yet be recognized.

**Conclusions**

It is clear from the results of this project that any interpretation of a zooarchaeological assemblage must exercise great care in interpreting bone breakage, and cannot safely make sweeping interpretations based on simple patterns. For example, Otto's now famous one-pot meals, based entirely on fragmentation information, seem unreasonably simplistic given the immense number of factors other than cooking that influence fragmentation (1984). Though less extreme, other interpretations based on breakage, such as characterization of bones as dry or fresh when broken (e.g., Bar-Oz and Dayan 2002) should also be questioned. Cooking methods and other such processes simply do not result in obvious diagnostic attributes which would allow a researcher to identify them reliably, but rather in more general breakage trends. More obviously, the influence of freezing suggested by this study calls into question any experimental study that at one point or another froze their material. This factor is not generally reported by such studies (though it sometimes is, e.g., Pearce and Luff 1994) because its potential importance was not previously known, but can be presumed to have generally been the case if the study was undertaken in a more laboratory setting. Verification and further
in investigation of this influence is, I believe, the most important future work suggested by this study.

However, the fact that a relationship between cooking and breakage is at all visible leads me to believe that, were it possible to control for enough variables, to completely characterize each bone, and preferably to avoid freezing entirely, it would probably be possible to create a model based on this type of study that would have very good internal predictive power. However, I contend that there would, ultimately, be little to be gained from doing so in terms of creating a useful predictive model or comparative collection. The ultimate goal of this type of research is to provide zooarchaeologists with an interpretive tool that would allow them to better understand archaeological assemblages, and if an experimental data set must be so rigorously controlled in order to demonstrate this relationship, then the odds of being able to actually apply such a model to archaeological bone in a meaningful way is very low. The factors that influence bone breakage are simply too many and too complicated to allow the researcher to control for all of them and actually address cooking with any confidence. Researchers will meet with more success in interpreting cooking using other methods, such as through patterns in elements represented and the spatial distribution of them, as in Speth 2000.

That said, there are more general interpretive tools that studies similar to this one might be able to produce. As I have described, a number of factors seem to influence general trends in bone breakage – broadly defined features that are more or less likely to occur or are more or less pronounced depending upon a variety of factors. These most likely include taxon and element, as well as other factors including cooking, the diet, age
at death, and health of the animal, and so on. None of these influences leave specific, distinctive marks on the bones, but they do appear to increase the probability that various types of breakage will occur. Another researcher examining the patterns of dentition resulting from human and dog chewing of bones found themselves in a similar situation, such that some chewing marks were more likely to be the result of one group or the other but were not exclusive to them in most cases (Carver 1997, unpublished). The solution was to place the marks on a continuum, with some being quite close to one side and others nearer the middle, where their presence only slightly favored one side or the other. The situation here is more complicated, because breakage information cannot be readily reduced to a bipartite division of this type, but analogous techniques might be used to characterize various aspects of breakage if studies were done to more completely understand the trends. This would not necessarily directly improve the archaeological identification of cooking, but it could help researchers to be aware of the types of factors that are more likely to be manifested by bones that have undergone various processes. Of course, such tools could only be confidently produced if a huge number of different factors had been studied and characterized, from events in an animal's life to weathering and site formation processes. Nevertheless, the potential value of such interpretive tools is immense, and argues strongly for the utility of future research.

Acknowledgments

My thanks go first and foremost to Joanne Bowen, whose expertise, assistance, and enthusiasm were critical to the success of this project from its earliest stages. My thanks go also to my two other committee members, Martin Gallivan and Lorena Walsh,
for their help and comments, as well as to Sebastián Salgado-Flores and William Foster, my two primary assistants. I am also immensely grateful to Matthew Hanson, who devoted a great deal of time and thought to this project and without whom the statistical modeling performed would have been impossible. Furthermore, I must thank Jay Gaynor, Frank Clark, and the rest of the staff at the Colonial Williamsburg Foundation Department of Historic Foodways for their helpful suggestions and donations, as well as Steve Archer, Steve Atkins, Andrew Edwards, and the other volunteers and staff at the Colonial Williamsburg Foundation Department of Archaeological Research for all their help and for allowing me to carry out my sometimes unpleasant work in their midst. Other contributors to the success of this venture who deserve thanks for a variety of reasons include Ken Schwartz, Richard Nicoll, Rebecca Schneider, Matthew Liebmann, and the many people who donated bones to the project.
Works Cited


the Study of the First Americans, 1989.


**Primary Sources**


Data Appendix Notes

1. This refers to the presence or absence of meat at the time of chopping. This extra cushion may well alter breakage.

2. Only a small selection are unfrozen, but this is a variable which has never been investigated and is therefore possibly important, especially as most archaeological bones were not frozen.

3. Many of our cattle bones had been in storage for roughly 10 years, and some seemed particularly brittle as a result.

4. In many bones which had been cut previously, they were observed to break preferentially towards the existing cut.

5. The difficulty of assessing this quantitatively suggests the qualitative descriptions which I have given. I believe that fragmentation may be an important variable in this study.

6. The division of fragmentation data into these five categories reflects my attempt to record this data quantitatively, though I am aware that processing has biased it somewhat. Weights are all given in grams.

7. This reflects fragments which were too tiny to be recovered, as they were so easily carried by wind, so easily lost, etc. Their presence or absence is based upon notes taken at the time of chopping.

8. Certainly, the thickness of bone will have an influence on the ease of breaking it, and possibly on the pattern of its break. Given in cm.

9. This is also of necessity a qualitative assessment, though the maximum lateral distance of cracking is also measured. I believe that this may be an important variable.

10. A red number indicates that cracking extended all the way through the bone, and that the number given is simply the distance to the end of the bone.

11. A type of break long believed to be related to butchery, it has been shown to occur naturally in many bones, especially the tibia and femur. However, it may yet be relevant here.

12. These three categories are measurements of the depth of the three main components of a break - the strike platform, break, and shatter. These components may vary in size with cooking method.

13. Was cancellous bone present at the break location? The attempt was generally made to avoid it, though this was not always possible. If it is present, did the break travel through or along it?