The Effects of Collagen Rehydration on Postmortem Fracture Morphology: Implications for the Perimortem Interval

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

The purpose of this thesis was to explore the effect of water saturation on the fracture morphology of dry bones – specifically, this research sought to determine if rehydrating dry bones would cause skeletal material to fracture in a manner similar to fresh bones. This question has important implications for the interpretation of bone trauma, yet no previous studies have explored this topic. To answer this question, samples of dry faunal bones were soaked in water until they reached maximum saturation and then they were broken with a bone fracture apparatus. The fractures produced on these rehydrated bones were later compared to those produced on both dry bone and fresh bone samples to determine if there was any significant change in the biomechanical behaviour of the rehydrated group. The results of the analysis showed that the rehydrated flat bones were more likely to fracture in a manner consistent with the fresh bone group for some fracture traits (e.g. number of fragments produced, fracture angle, incomplete fracturing). Among the sample groups that consisted of highly-weathered remains, there was very little significant difference between bones that were broken while dry and bones that were broken after being rehydrated. These results suggest that water saturation may affect fracture morphology in dry bones provided at least some of the bone's organic components (i.e. collagen) have been preserved. The significant degree of overlap between the sample groups underscores the problem of estimating the timing of traumatic events on skeletal elements based on discreet categories such as "perimortem" and "postmortem". Anthropologists should consider adopting a system that describes bone trauma with regard to the state of the material at the traumatic event (i.e. wet or dry) and within the context of the depositional environment.

Acknowledgements

I would like to extend my heartfelt thanks to Dr. Maria Liston, whose inspirational instruction and guidance made this thesis research possible. Thank you for believing in my research and for your generous donation of faunal bones to the experiment portion of this study. I am incredibly grateful to have had the opportunity to study at the University of Waterloo as your graduate student and to benefit from your knowledge and experience.

I would also like to thank Newmarket Meat Packers for their donation of fresh lamb bones to my experiment. I greatly appreciate your professionalism and your willingness to coordinate with me. Your kind donation allowed me to complete this study.

Lastly, I would like to thank Dr. Alexis Dolphin and Dr. Bonnie Glencross for taking time out of their busy schedules to participate on my graduate committee. Your service and expertise are greatly appreciated and your comments and feedback were extremely helpful.

Dedication

To my family – Mum, Dad, Wendy, Bob, Adam, and your families. I cannot express how much your care and support has meant to me over the years. You encouraged me during the difficult times and gave me the courage to keep moving forward. You made all of this possible and I would not be here without you.

Thank you for always being there for me even when I could not be there for you.

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CHAPTER 1

Proposed Venue of Publication

For this thesis I conducted experimental research into the effects of water absorption on the biomechanical response of skeletal material to low-velocity impact forces and its impact on fracture production. A study of this kind has not been previously attempted, therefore this exploratory study will provide important information for several subfields of physical anthropology (e.g. forensic anthropology, bioarchaeology, and paleontology). A series of experiments on faunal specimens demonstrated that dry bones that have at least partially maintained their organic components (i.e. collagen), when rehydrated, are more likely exhibit fracture traits that are typically associated with fresh fractures. These results draw attention to the fact that skeletal material exists on a continuum of “freshness”, thus rendering the classification of trauma into mutually exclusive categories of “perimortem” and “postmortem” problematic. Some authors have suggested that this issue could be resolved by describing skeletal trauma with regards to the physical state of the bone when the fracture was produced (e.g. “wet” or “dry”) rather than in relation to the death event (e.g. “perimortem” or “postmortem”) (7,9,20,21). “Wet” is often used as a synonym for “fresh”. I tested whether rehydrated dry bone could recover the characteristics of fresh bone.

The selected venue of publication for this research is the *Journal of Forensic Sciences*. This peer-reviewed journal is the official publication of the American Academy of Forensic Sciences (AAFS) and provides research from a vast array of subdisciplines in the forensic sciences, such as biological anthropology, pathology, and biomechanics. The AAFS describes itself as a multidisciplinary professional organization that seeks to advance science and its application to the legal system, as well as promote education, foster research, improve practice, and encourage collaboration in the forensic sciences.

My research demonstrates that the biomechanical properties of dry bones may be restored to a fresh-like state provided that enough of the skeletal material’s organic components have been preserved. This information has many important implications for skeletal analyses in forensic investigations. Specifically, my research suggests that traumatic injuries that appear to have taken place on fresh bones could have potentially taken place many years after an organism’s death, provided environmental conditions are such that the bones’ organic components are preserved. This information will elevate the accuracy, precision, and specificity in trauma interpretation, as well as encourage collaboration between forensic anthropologists and biomechanical engineers in trauma analysis.

Public Issues

This research has significance both in the field of forensic science and in bioarchaeology. Evaluating skeletal trauma is essential in forensics investigations to reconstruct death events and to determine whether or not a crime has taken place. In bioarchaeology, trauma analyses may help reconstruct historical events or shed light on cultural practices, which in turn deepen our understanding of human history.

Trauma analysis is one of the most important aspects of a forensic anthropologist’s role in a death investigation, and estimating the timing of traumatic events is critical (1,3,30). Perimortem injuries are of particular interest to forensic anthropologists, as these are typically identified as occurring at or near the individual’s time of death (1,6). The correct diagnosis of a perimortem injury is necessary for the accurate reconstruction of death events, including the cause and manner of death and whether or not foul play was involved (1,4,6,43). However, associating perimortem trauma with death events can be problematic, as the perimortem interval can be ambiguous and may be influenced by a number of environmental factors (3,6).

In recent years, forensic anthropologists have been increasingly called upon to give courtroom testimony on skeletal trauma in a wide range of forensic cases, from violent murders to terrorist attacks, to genocide and crimes against humanity (30). In particular, evaluating trauma on skeletal remains in mass burials may also be confounded by moisture, as fluids from decomposing bodies may be retained within the core of a group of bodies in mass graves (1,3). Failure to differentiate between postmortem alterations and death-related injuries in a forensic investigation may carry serious consequences, such as misleading investigators or even wrongful convictions (1,8,10,20). Miscarriages of justice ultimately cause society to lose faith in the justice system – either by convicting the innocent or by failing to convict a culpable individual. Therefore, any new information that may help increase the accuracy and precision of existing analytical tools are of vital importance to the administration of justice and, in turn, maintaining the public's faith in the justice system.

Bioarchaeologists also conduct analyses on skeletal trauma to reconstruct death events surrounding individuals in historical contexts. These interpretations may shed light on historical events and cultural practices. For example, perimortem fractures on skeletons in the archaeological record may provide evidence of patterns of violence – such as warfare and domestic violence – in historic and prehistoric societies (5,24,37,44-47). Such information may help researchers understand modern violence from an appropriate cultural-historical perspective, which in turn may provide answers to questions about human aggression (37,44-46). Additionally, the presence of postmortem fractures on buried remains could serve as evidence of exhumation and secondary internment (30,48). Many cultures throughout history have engaged in postmortem manipulation of the dead, and these mortuary behaviours may grant insights into the spiritual beliefs and customs of ancient civilisations, thus contributing to the body of knowledge of human history and cultural development (38,44-46,49,50). However, trauma on skeletons buried in moisture-rich environments, such as the infant well burials observed in Athens, Greece (51), may be difficult to interpret as the wet environment may confound efforts to identify perimortem trauma as opposed to excavation damage.

Trauma analysis has also played an important role in paleontological research conducted on fossils of our non-human ancestors. Recently, a team of scientists at the University of Texas at Austin conducted trauma analyses on the remains of Lucy, the 3.2-million-year-old skeleton of an australopithecine first discovered in Ethiopia in 1974. Based on the numerous compressive and green-stick fractures found on several elements of Lucy's skeleton, the researchers concluded that she probably died from injuries sustained from a fall from a tree (52). If they are correct, this discovery may shed light on how our non-human ancestors interacted with their environment (52). However, the Austin research team has been criticised for failing to explore alternative explanations for the fracture patterns observed on Lucy's skeleton (53). Furthermore, the skeleton's proximity to nearby rivers or exposure to heavy summer rainfalls may have increased the ground moisture and extended the perimortem interval of the remains. Therefore, skeletal rehydration and its impact on the perimortem interval should be a matter of consideration even in situations involving ancient hominid remains.

The results of this research underscored this issue, as it demonstrated that fractures with perimortem traits could be produced on bones that were over two decades old. This would suggest that the only requisite conditions for the production of “perimortem” trauma are at least partially-preserved organic components and a moisture-rich environment. Therefore, the timing of traumatic events may be difficult to determine accurately not only in submerged remains, but also in remains that are subjected to “wet” environmental conditions, such as bodies that have developed adiopocere, that have been buried beneath the water table, or that have been buried in areas susceptible to flooding (1,3).

The correct evaluation of skeletal trauma is essential not only to reconstructing the events surrounding the death of an individual in a forensic investigation, but also to understanding ancient human cultures and practises, human evolution, and human adaptation. Yet there appear to be no previous studies that examine the impact of rehydration on the morphology of bone fractures. My research will address this issue, and help increase the accuracy and precision of such analyses.

CHAPTER 2

Introduction

Trauma analysis is an important area of study within the field of forensic anthropology. By looking at specific traits of fracture morphology, anthropologists classify the timing of skeletal injuries as occurring within three broad intervals – antemortem, perimortem, and postmortem. *Antemortem injuries* are those that take place before death and may be recognised by the presence of active healing at the site of the fracture. *Perimortem trauma* is usually used to refer to injuries that occur at or around an individual's time of death. *Postmortem trauma* refers to injuries that take place after death and are typically associated with taphonomic processes such as weathering, animal activity, and excavation damage.

Distinguishing between perimortem and postmortem trauma is a crucial part of a forensic investigation. The accurate timing of traumatic injuries is necessary in order to reconstruct death-related events and post-depositional modifications (1-5). Perimortem trauma is an area of particular interest, as the information gleaned from these fracture patterns may provide useful insights into the cause and manner of death (3-6). Diagnosing perimortem trauma in death investigation can have serious legal consequences, and failing to properly reconstruct death events can derail an investigation and could even lead to wrongful convictions (1,2,7-9). Thus, it is vitally important for anthropologists to understand the mechanisms that cause trauma, and the intrinsic and extrinsic factors that affect fracture morphology on fresh and dry bones. However, the perimortem interval is not a clearly demarcated phase in the death process. It is an ambiguous period that may last for an unspecified amount of time, depending on the conditions of the environment in which the bones are found (3,5,6). This ambiguity can make it difficult to accurately determine the timing of certain injuries on bones (2).

Dry bones fracture differently from fresh bones because they manifest a different physical state which ultimately affects the mechanisms and appearance of a fracture (2,3,5,9,10). Fresh or living bone contains a significant amount of moisture, body fats, and collagen, which affect how fractures will form as force moves through skeletal material (2,5). Following death, bones will gradually lose these fresh properties and become dry and brittle. However, the rate at which bones lose these fresh qualities depends on the depositional environment. Furthermore, bones may absorb moisture from the surrounding environment, which can sometimes cause dry bones to mimic the qualities of fresh bones in terms of weight and appearance. However, it is not clearly understood how this skeletal rehydration impacts the propagation of postmortem fractures on skeletal elements (2,10). The primary goal of this research is to discover if skeletal rehydration will cause dry bones to fracture in a manner more consistent with fresh bone (perimortem) fractures. A secondary goal of this research is to discover what (if any) patterns of fracturing can be observed on rehydrated remains and if such fractures can be distinguished from fresh (perimortem) and dry (postmortem) bone fractures.

The Biomechanics of Skeletal Material

Biomechanics is the study of forces and energies on biological systems. Understanding the biomechanical behaviour of skeletal material is necessary in order to understand how fractures propagate on bone (3,9-12). This, in turn, necessitates a deeper understanding of bone histology and composition.

Bone matrix is a dynamic, composite material comprised of organic and inorganic materials (10,13-16). The organic matrix of bone, which gives bone its flexibility and elasticity, is composed primarily of Type I collagen fibres (90%) surrounded by a gel-like extracellular matrix (3,10,11,13-15,17-19). Embedded within these collagen fibres are inorganic minerals, that impart stiffness and rigidity to bone, and consist primarily of hydroxyapatite crystals (10,11,13-15,17,18,20).

Macroscopically, there are two types of bone tissue – dense cortical bone and porous trabecular bone. The distinctive structures of these tissues influence the biomechanical properties of skeletal material, causing them to react differently to applied forces (10,21,22). Cortical bone forms the hard outer surface of bones, particularly on the diaphyses of the long bones, in varying degrees of thickness (depending on functional necessity) (16,17). The greater stiffness of this material allows it to withstand greater axial compression before failure (fracture), however this makes it more sensitive to strain (deformation in response to an external force) (10,21). Trabecular bone consists of thin plates of interconnected bone (*trabeculae*) that are encased within the cortical bone (10,16,17). This material is more flexible than cortical bone and serves to increase the load-carrying capacity of a bone without increasing mass (16,21). The complex organisation of cortical bone and trabecular bone within skeletal elements is adapted for maximum energy absorption with minimal structural trauma (16).

The composition of skeletal material varies between types of bones and types of bone tissues, and may also be affected by individual traits such as species, age, sex, and pathology (10,17,23,24**Error! Reference source not found.**). Different vertebrate species have bones of varying size, composition, and geometry, which result in variations in strength and structure (1,10,21). Furthermore, subadult bone has been shown to have a greater percentage of collagen than adult bone (25), with different ratios of mineral and organic materials (15,26) and larger and more extensive Haversian canals (10,27). These differences make subadult bone more flexible and cause them to absorb impact forces better than adult bone (14,25,28).

Due to the elastic nature of skeletal material, bones will deform when subjected to mechanical loading forces, and may return to their original forms when loads are released (10,18,29). There are three main phases of fracture production in skeletal material – elastic deformation, plastic deformation, and failure (9-11,21,30). Elastic deformation is the state from which skeletal material may recover its original shape and dimension after loading stress is released (9-11,21,30). As the maximum elastic capacity of the bone is exceeded, the material enters the plastic deformation phase – a state from which the bone cannot return to its original form (9-11,21,30). Failure occurs when sufficient force is applied to a region of bone to allow a fracture to travel through the collagen fibres and produce a discontinuity in the bone tissues (9,10,30).

The morphology of bone fractures will vary depending on whether the skeletal material is dry or fresh when the fracture is produced. This experiment will focus on the six primary fracture traits – 1) number of fragments, 2) fracture angle, 3) margin outline, 4) surface texture, 5) radiating fracture lines, and 6) fracture classification. The purpose of this study is to compare the fracture patterns produced on fresh, dry, and rehydrated bones to determine if water absorption in dry skeletal material will alter the propagation of postmortem fractures in any significant manner.

Sample

The sample in this experiment included three broad groups of faunal bones – fresh butcher-grade lamb bone, dry well-preserved whole sheep bone, and dry mixed faunal fragments exhibiting extensive taphonomic weathering. Table 1 summarises the composition of the sample groups.

The dry sheep bones consisted of surface finds that had been retrieved from an agricultural setting and held within a controlled laboratory environment for approximately 20 years. This group was separated into two sample groups – Dry-Control and Rehydrated. These groups were further divided into two subgroups – long bones (femora, humeri, tibiae) and flat bones (crania, mandibles, scapulae, ossa coxae, ribs). The Rehydrated elements were soaked in water and were periodically weighed to track changes in mass due to water absorption. Following a period of 76 days, the elements ceased to exhibit any increases in mass, signalling that maximum saturation had been achieved.

The Fresh group consisted of butcher-grade lamb bones, which were donated by Newmarket Meat Packers Ltd. from Newmarket, Ontario. The bones were mechanically cleaned,

TABLE 1—*Sample Size*

Broad Groups	Sample Size	Maturity	Long Bones	Flat Bones	Irregular Bones
Rehydrated Group	76	41 adults 35 subadults	4 femora 3 humeri 4 tibiae	3 cranial bones 5 mandibles 4 ossa coxae 9 scapulae 44 ribs	None
Fresh Group	30	0 adults 30 subadults	8 femora	3 cranial bones 6 mandibles 13 ribs	None
Dry-Control Group	18	12 adults 6 subadults	1 femur 1 humerus 1 tibia	3 cranial bones 3 mandibles 1 os coxa 3 scapulae 5 ribs	None
Rehydrated-Weathered Group [Fragmented]	29	Unknown	1 tibia 4 unidentified long bone fragments	6 cranial bones 7 mandibles 4 ossa coxae 2 unidentified flat bone fragments	1 phalanx 1 long bone epiphysis 2 vertebrae 1 unidentified irregular fragment
Dry-Weathered Group [Fragmented]	29	Unknown	3 unidentified long bone fragments	7 cranial bones 7 mandibles 3 ossa coxae 4 unidentified flat bone fragments	2 phalanges 3 unidentified irregular fragments

removing the soft tissue, so that the bone surface was exposed. No attempt was made to remove the periosteal membrane or articular cartilage, as this would have damaged the bone surface and possibly compromised the analysis of the fractures. Unlike the other sample groups, this group consisted exclusively of subadult bones, although the bones of most of the butchered lambs approximated adult size.

The weathered bone fragments were included because the bones from the dry group had been stored within a controlled environment and therefore were not subjected to the same taphonomic processes (i.e. weathering, insect and animal activity, etc.) that skeletal remains are often subjected to following decomposition. The weathered bone group was included to determine if rehydration could impact fracture morphology even when the skeletal elements are extensively degraded. Since documented archaeological bone could not be used and destroyed for this project, this group was selected from a collection of surface finds from a variety of locations, which were held in the University of Waterloo's archaeozoological collection. While the largest fragments available were used, most of the elements were quite small and species and bone type could not be confidently assessed in every case. Previously fragmented edges were marked with ink prior to fracturing. This group was separated into two sample groups: Dry-Weathered and Rehydrated-Weathered. These two groups were further divided into three subgroups – long bones, flat bones, and irregular bones (vertebrae, epiphyses, phalanges). The Rehydrated-Weathered group was soaked in water for a period of 22 days (the smaller sample size and highly fragmentary nature of the elements allowed a shorter saturation period).

Methods

Fracture Production

A bone fracture apparatus was constructed in an effort to produce a comparable force of impact for each bone element (Fig. 1). However, the purpose of this initial study was to examine broken edges, not to study the mechanism and force needed to produce fractures. Each bone was measured and weighed prior to fracturing. Each element was struck by a cylindrical fracture mechanism weighing 2.804 kg – the composite weight of the 5-lb. drop weight (2.268 kg), the fracture mechanism, and the median rod. This weight was selected with the intention of producing enough force to produce a fracture on most of the elements while reducing the rate of

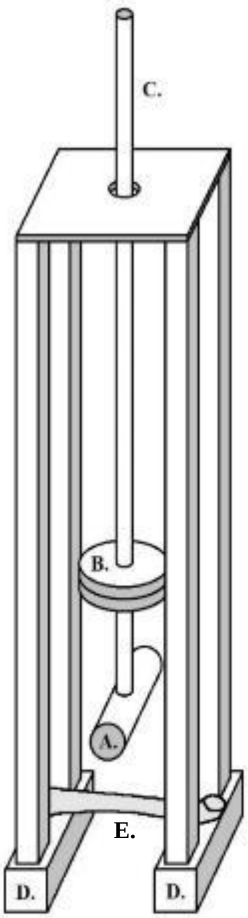


FIG. 1—*Bone fracture apparatus*
A. Fracture mechanism. B. Drop weight. C. Median rod. D. Support platforms. E. Sample

pulverisation among the smaller, dry elements. After a series of test trials, a drop height of 0.54 m above the point of impact was selected, once again with the intention of producing a sufficient fracture force whilst avoiding pulverisation among the dry elements. At these specifications, the fracture mechanism would strike the specimen with approximately 14.87 J of energy (final velocity = 3.26 m/s), producing a force of impact comparable to low-velocity blunt force trauma. In the event that the force of impact was insufficient to produce a fracture, the weight and drop height of the mechanism were gradually increased, up to 3.919 kg and 0.630 m respectively. In such cases, the apparatus could fracture the specimens with a maximum of 24.20 J of energy (max final velocity = 3.51 m/s).

While the apparatus could successfully fracture most of the specimens, 2 of the 11 Rehydrated long bones could not be fractured at the maximum energy output. Furthermore, all 8 of the Fresh long bones failed to fracture at this level. For these specimens, fractures could only be produced after manually striking them against the rounded edge of a steel hammer. For most of these specimens, several blows were required to produce a successful fracture. The ability of these specimens to absorb such levels of energy is most likely attributable to the presence of moisture within their structures. However, the durability of these specimens necessitated the use of uncontrolled forces to produce a fracture, which may have had unknown effects on the resulting fractures. While it would have been better to be able to control the force applied in all cases, the focus of this study was on the appearance of fractures, not the force required to produce them. It was necessary to produce fractures in each sample bone, regardless of the method required to do so. In conducting fracture analysis in forensic or archaeological contexts, it is normally impossible to know the exact force or mechanism that resulted in the fracture; the characteristics of fractures must be analysed without knowing or controlling for these variables. However, this suggests that less force is required to fracture rehydrated bones, even if the appearance of the resulting fractures resembles those on fresh bone. This indicates a potential avenue of future study.

All of the rehydrated elements were measured and weighed a second time following saturation to calculate each specimen’s water content. The mean masses of the Rehydrated long and flat bones were compared to the mean masses of the Fresh long and flat bones to determine if there was any significant difference in weight between the Fresh and Rehydrated subgroups. The mean masses of the Rehydrated skeletal elements were compared with the mean masses of the elements in the Rehydrated-Weathered groups to determine if there was consistency in moisture content among the “wet bone” subgroups. After fracturing, these bones were allowed to air-dry to reduce the risk of handling damage and mold growth.

To determine if any decalcification took place within the rehydrated remains during the saturation process, samples were taken from the water in which they had been soaking and tested using an API® Aquarium Pharmaceuticals water quality test kit for calcium (Ca^{2+}) levels. If calcium minerals had been leeched from the bone during the soaking process, it is expected that the water would reflect an increase in its calcium levels. The water samples were tested and compared against a sample of municipal water from the same sink that was used to fill the water buckets. A test of both samples revealed equal levels of calcium between the bucket water and the municipal water (100 mg/L). Therefore, any changes to these bones' biomechanical behaviour cannot be attributed to bone softening brought on by decalcification.

Analysis

There are a number of morphological traits in skeletal fractures that are used to distinguish between perimortem and postmortem fractures (7,31,32). Perimortem fractures are understood to occur on bones while the skeletal material is still fresh (or "green"), while most of its organic matrix (i.e. collagen) remains intact, thus maintaining its flexibility and elasticity (3,5-7,10**Error! Reference source not found.**,21,33). Postmortem fractures occur on bones that have lost most of their moisture and organic properties (5,7,10,21,30). Skeletal material will respond differently to stress based on its moisture and collagen content, as these affect the flexibility and tensile strength of the bone (1,10,20,30,33).

This analysis focussed on six fracture traits – 1) the number of fracture fragments, 2) the fracture angle (angled or perpendicular to the cortex), 3) shape of the fracture margin outline, 4) texture of the fracture surface, 5) the appearance of radiating fracture lines, 6) and the fracture classification. These traits were selected as they are among the most commonly addressed features in published studies of perimortem and postmortem fracture morphology (1-3,6,7,12,20,25,29-40) and are relatively simple to evaluate macroscopically.

1. Fracture fragments. Postmortem fractures on dry bones typically produce several small fracture fragments, while fresh bone produces a smaller number of fragments when broken (3,7,30). The number of fragments produced in each element was recorded for comparison. For the purposes of this analysis, fragment counts only included fracture fragments larger than 0.5 cm^2. Fragments smaller than this typically included pulverised remains that could not be accurately analysed or accounted for, and generally would be lost in archaeological, and perhaps forensic, contexts.

2. Fracture angle. Fracture angle refers to the angle created by the fracture surface in relation to the cortical surface of the bone. Acute and obtuse fracture angles are typically associated with perimortem fractures (Fig. 2), while right angles (also called *perpendicular* angles) are usually observed on postmortem fractures (Fig. 3) (1,6,7,10,30,32).

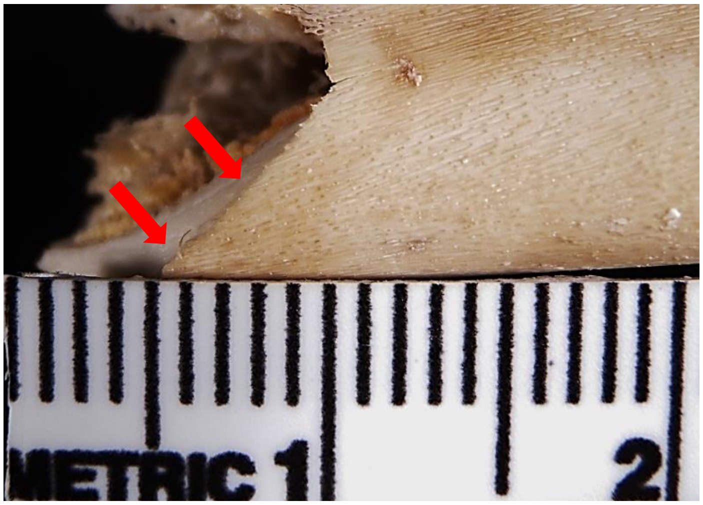


FIG. 2—*Oblique angled fracture (Fresh mandible). Photo by author.*

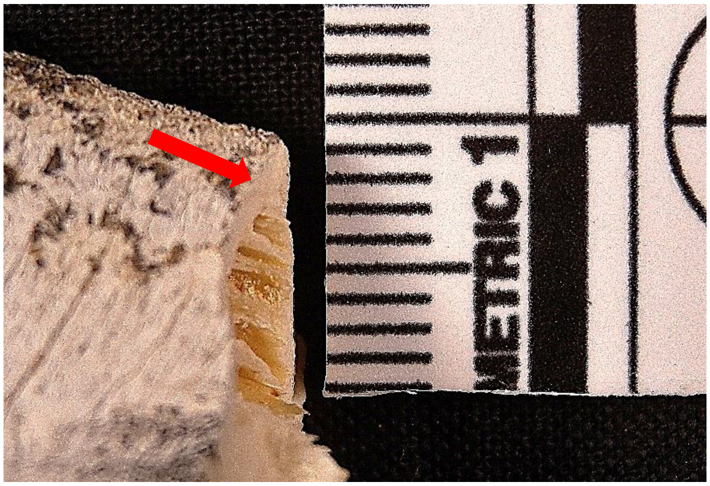


FIG. 3—*Perpendicular fracture angle (Dry-Weathered mandible). Photo by author.*

3. Margin outlines. Margin outlines are the shape of the fractured edge of a skeletal element. Irregular (Fig. 4), curved (Fig. 5), and V-shaped outlines (Fig. 6) are usually associated with perimortem fractures (3,6,7,30). Flat, relatively straight outlines (Fig. 7) are often attributed to postmortem fractures (1,30). Intermediate fractures, which bear a combination of fresh and dry traits, are characterized by a stepped outline (Fig. 8) (7). An additional outline that was observed amongst the long bones included a wedge-like, or "half-butterfly" fracture (33) (Fig. 9).

FIG. 4—*Irregular fracture outline (Fresh mandible). Photo by author.*

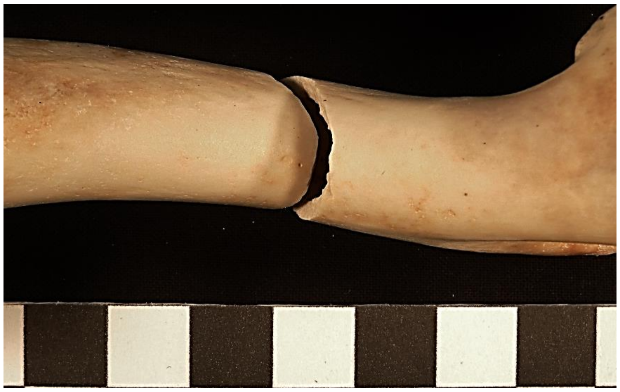


FIG. 5—*Curved fracture outline (Dry-Control humerus). Photo by author.*

FIG. 6—*V-shaped fracture outline (Fresh rib). Photo by author.*

FIG. 7—*Flat fracture outline (Rehydrated-Weathered long bone fragment). Photo by author.*

FIG. 8—*Intermediate fracture outline (Dry-Control mandible). Note the combination of flat and irregular traits in this outline. Photo by author.*

FIG. 9—*Half-butterfly fracture outline (Fresh femur). Distinguished by a square or rounded wedge-shaped tension fracture. Photo by author.*

4. Fracture surfaces. Perimortem fractures tend to have sharp, smooth fracture surfaces (Fig. 10) (1,6,7,10,30). At the microscopic level these surfaces may appear rough and string-like, as fresh bone fractures tend to follow the predominant direction of collagen bundles (Fig. 11) (7,30). Postmortem fractures tend to have rough and uneven surfaces (Fig. 12) (1,2,6,7,10,30,32). These surfaces will also appear stepped or roughened at the microscopic level, as dry bones tend to fracture transversely through the collagen bundles (Fig. 13) (7). Some of the elements exhibited mixed traits of smooth and rough textures along a single fracture surface and were thus categorised under the intermediate classification of "mixed".

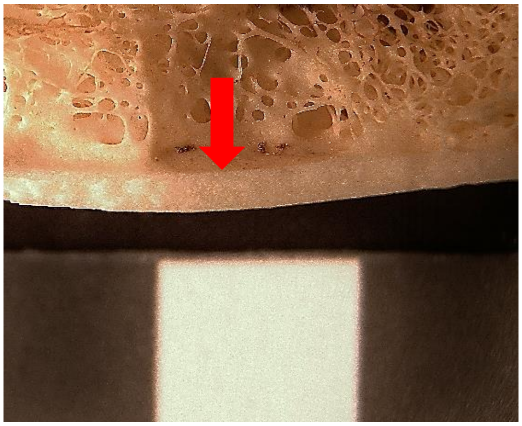


FIG. 10—*Smooth fracture surface (Dry-Control femur). Photo by author.*

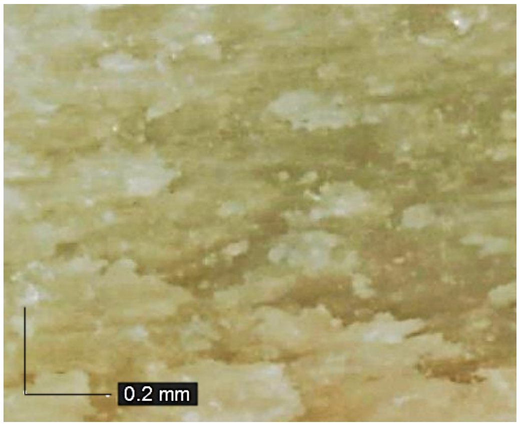


FIG. 11—*Microscopic view of a smooth fracture surface (Dry-Control humerus, 140× magnification). Photo by author.*

FIG. 12—*Rough fracture surface (Dry-Weathered mandible). Photo by author.*

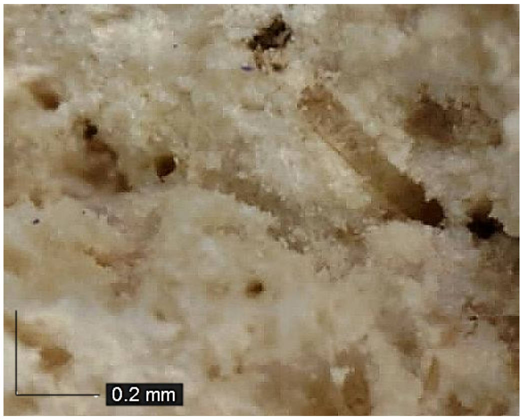


FIG. 13—*Microscopic view of a rough fracture surface (Dry-Weathered cranium, 135× magnification). Photo by author.*

5. Radiating fracture lines. Perimortem fractures are usually characterised by straight or curved radiating fracture lines near the point of impact (30,32). Postmortem fractures are usually thought to be distinguished by a lack of fracture lines, however dry bones may also exhibit a smaller number of discontinuous fracture lines (6,30). Additionally, perimortem fracture lines typically terminate at or near the epiphyses of long bones, while postmortem fractures do not, and may continue through the joint surfaces (20).

6. Fracture classifications. Fracture classifications refer to the overall shape and appearance of the fractured bones. As fracture type is largely dependent on the morphology of the bone, it was therefore necessary to record separate classifications for different types of skeletal elements. The Fresh, Rehydrated, and Dry-Control groups were separated into four subgroups – 1) Cranial bones, 2) mandibles, scapulae, and ossa coxae, 3) long bones, and 4) ribs. Due to their highly fragmented nature, fracture classifications could not be evaluated on the Dry-Weathered and Rehydrated-Weathered groups.

Cranial fractures were classified as comminuted (broken into multiple fragments), linear (with relatively straight or angular fractures) (Fig. 14), depressed (having a "caved-in" portion of the bone's cortex), or stellate (a "star-shaped" fracture with multiple radiating fracture lines) (Fig. 15) (10,34-37).

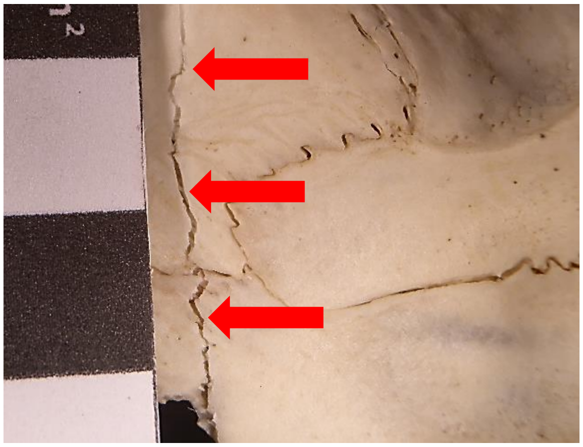


FIG. 14—*Linear cranial fracture (Dry-Control maxilla). Photo by author.*

FIG. 15—*Stellate cranial fracture (Dry-Control cranium). Photo by author.*

Fractures on the **mandibles**, **scapulae**, and **ossa coxae** are classified as comminuted (three or more fragments), non-comminuted (less than three fragments), or incomplete (where the fragments maintain some continuity) (Fig. 16) (10,38). Incomplete fractures include "bowing" fractures (where there is no macroscopically visible damage to the cortex), "buckle" fractures (where damage to the cortex is visible at the point of impact), and "greenstick" fractures (where damage to the cortex is visible on the side opposite the point of impact) (10,25). Incomplete fractures are indicative of a high moisture content and are more commonly observed in the perimortem interval (7,10). They have also been thought to occur more commonly in children due to the higher ratio of organic to mineral components in immature bone (10,24,28,38). However, a study by Love and Symes (2004) found incomplete fractures occurring on the ribs of children and adults aged 21 to 76, with no greater frequency among any specific age group (41).

FIG. 16—*Incomplete fractures (Rehydrated scapula; Rehydrated rib). Photos by author.*

Long bone fractures may be categorised under five different classifications – oblique fractures (Fig. 17), butterfly fractures (Fig. 18), spiral fractures (Fig. 19), incomplete fractures, and transverse fractures (Fig. 20). Oblique fractures break on an angle to the long axis and are typically the result of perimortem injuries (7,10,29,38-40). Butterfly fractures occur when bone-bending forces create compression and tension fractures on the surface of the bone, and are characterised by the presence of a triangular-shaped breakaway spur (9,20,31,33,39,40). Butterfly fractures usually occur in the perimortem interval, however such fractures have been observed on dry bone as well (6,7,20,31). Spiral fractures, as the name suggests, are fractures that spiral around the diaphysis of the long bone and typically occur in the perimortem interval (2,7,10,33,38-40). Spiral fractures are often disrupted by the longitudinal orientation of collagen fibres, resulting in bone fragments that tend to be longer than they are wide (7). Transverse fractures occur perpendicular to the long axis of a bone, and typically occur during the postmortem interval (1,2,6,7,10,26,30,33,38-40).

Rib fractures were categorised under three different fracture classifications – comminuted, non-comminuted, and incomplete.

FIG. 17—*Oblique fracture (Dry-Control humerus). Photo by author.*

FIG. 18—*Butterfly fracture (Rehydrated femur). Photo by author.*

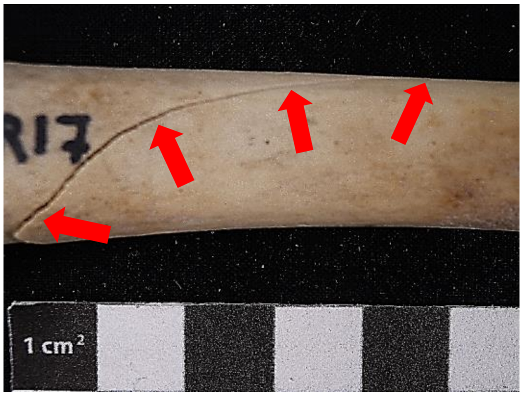


FIG. 19—*Spiral fracture (Rehydrated tibia). Photo by author.*

FIG. 20—*Transverse fracture (Rehydrated femur). Photo by author.*

Table 2 summarises the fracture traits that were analysed for this study and the typical observations for perimortem and postmortem injuries.

TABLE 2—*Fracture Traits Summary*

Trait	Perimortem	Postmortem
Number of fragments	Fewer, larger fragments	Several small fragments
Fracture angle	Acute or obtuse angle between the fracture surface and the cortex	Fracture surface forms a right angle with the cortex
Margin outline	Irregular, curved, or V-shaped	Flat
Fracture surface texture	Smooth	Rough
Fracture lines	Radiating fracture lines that terminate at or near the epiphyses in long bones	Fewer, discontinuous fracture lines
Fracture classifications	Oblique, butterfly, spiral, incomplete	Transverse

Additional observations. During the analysis process, three additional potentially diagnostic traits were observed among the Fresh and Rehydrated groups – peeling/flaking of the periosteum in the Fresh remains, longitudinal splitting near the areas of impact in the Fresh and Rehydrated ribs, and unique "tearing" secondary fractures among the Rehydrated flat bones.

Statistics. To determine if the observations were meaningful, a series of statistical analyses was carried out. The variances for the average numbers of fracture fragments in each subgroup were tested using a two-sample F-test in Microsoft Excel 2013. The groups were then compared using a two-tailed *t*-test for comparing two independent means at a 95% confidence level ($\alpha = 0.05$) using Excel's data analysis feature. For the rest of the observations, chi-square tests and Fisher's exact tests were applied using the XLSTAT add-on for Excel. Results where $p < 0.05$ were considered statistically significant. Fisher's exact test of independence is useful when working with small sample sizes to directly calculate whether or not the given observations would be expected to be seen by chance, though it is more commonly used on 2×2 contingency tables. The statistical formulae used in each analysis are summarised in Table 3.

TABLE 3—*Statistical Formulae*

Statistical Analysis	Formula	
F-test	$\left(F = \frac{S_1^2}{S_2^2}\right)$	Where S_1^2 = variance of sample 1 S_2^2 = variance of sample 2
t-test	$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}}$	Where $\bar{X}_1$ = mean of sample 1 $\bar{X}_2$ = mean of sample 2 S_1^2 = variance of sample 1 S_2^2 = variance of sample 2 n_1 = number of subjects in sample 1 n_2 = number of subjects in sample 2
Chi-square test	$\left(\chi^2 = \Sigma \frac{(\mathrm{O} - \mathrm{E})^2}{\mathrm{E}}\right)$	Where Σ = sum O = observed value E = expected value
Fisher's Exact test	$\left(p = \frac{(a+b)!\,(c+d)!\,(a+c)!\,(b+d)!}{a!\,b!\,c!\,d!\,n!}\right)$	Where a, b, c, d = cell values $n = a + b + c + d$

Observations

Mass

The mean masses of the Rehydrated elements following saturation were generally lower than the mean masses of the Fresh elements (Table 4). The differences in mean mass were statistically significant among the Fresh and Rehydrated long bones ($F_{0.05,(2),7,10} = 1.320$; $t_{0.05,(2),20} = -5.220$, $P<0.001$) and ribs ($F_{0.05,(2),43,12} = 1.492$; $t_{0.05,(2),55} = -3.006$, $0.001<P<0.01$). However, these differences were not statistically significant among the Fresh and Rehydrated mandibles ($F_{0.05,(2),4,5} = 3.535$; $t_{0.05,(2),9} = -0.458$, $P>0.10$). Statistical testing could not be carried out on the crania, scapulae, and ossa coxae due to lack of data. The variations in mass may be partially attributable to the presence of minimal amounts of soft tissues on the Fresh bones as well as size variation among the sample elements.

TABLE 4—*Comparison of Mass in Grams in Fresh and Rehydrated Remains*

	Fresh (g)			Rehydrated (g)		
Element	N	$\bar{X}$	SD	N	$\bar{X}$	SD
Crania	3	419.00*	--	3	208.00*	--
Mandibles	6	50.00	6.93	5	47.20	13.03
Scapulae	0	--	--	9	53.22	38.74
Ossa Coxae	0	--	--	4	100.00	54.48
Long Bones	8	180.50	23.16	11	58.27	20.16
Ribs	13	14.85	3.65	44	10.77	4.46

Water Mass Increase After Rehydration

	Rehydrated			Rehydrated-Weathered		
Element	N	$\bar{X}$	SD	N	$\bar{X}$	SD
Long Bones	11	28%	0.09	5	32%	19.18
Flat Bones	65	30%	0.12	19	25%	17.39
Irregular Bones	0	--	--	5	33%	23.51

N = number of elements, $\bar{X}$ = mean, SD = standard deviation

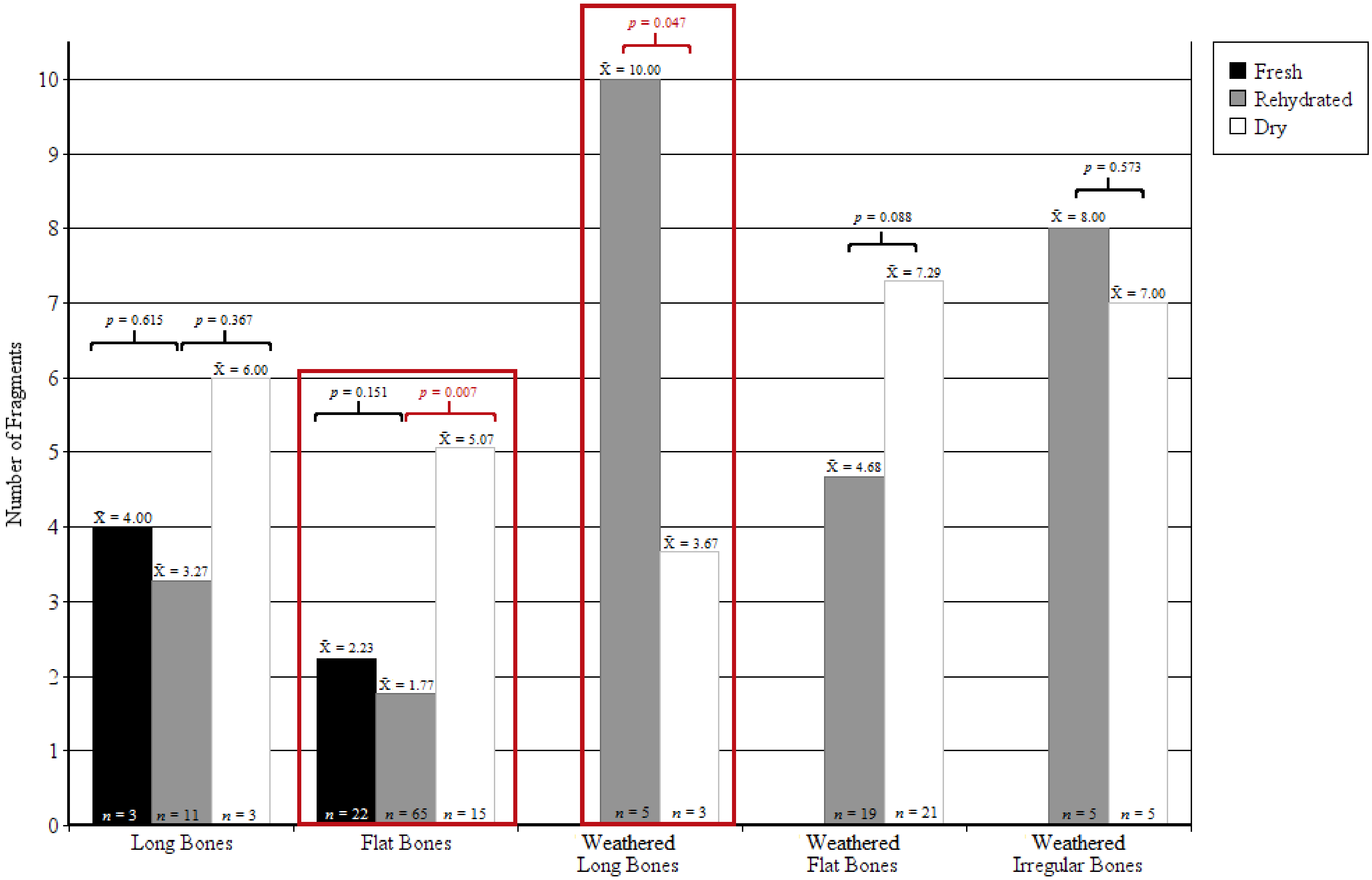
*These figures each represent the weight of one complete cranium before they were disarticulated into three separate sections, which were individually labelled and fractured.

The Rehydrated and Rehydrated-Weathered elements showed very similar increases in mass after being saturated with water (around 25% to 33% in both groups). The differences in the mean mass increases were not statistically significant among either the long bones ($F_{0.05,(2),4,10} = 4.183$; $t_{0.05,(2),5} = -0.429$, $P>0.10$) or the flat bones ($F_{0.05,(2),18,64} = 1.896$; $t_{0.05,(2),24} = 1.043$, $P>0.10$). Statistical testing could not be carried out on the irregular bones due to lack of data. These results indicate that any variations in fracture morphology between the Rehydrated and Rehydrated-Weathered groups are not likely to be due to variations in moisture content between the groups.

1. Fracture Fragments

The mean number of bone fracture fragments (Fig. 21) produced in the Rehydrated flat bones ($\bar{X} = 1.77$) was found to be significantly lower than those produced in the Dry-Control flat bones ($\bar{X} = 5.07$; $F_{0.05,(2),14,64} = 11.33$; $t_{0.05,(2),15} = -3.140$, $0.001<P<0.01$). Among the weathered groups, the number of fragments produced by the Rehydrated-Weathered long bones ($\bar{X} = 10.00$) was significantly higher than those produced in the Dry-Weathered long bones ($\bar{X} = 3.67$; $F_{0.05,(2),4,2} = 3.692$; $t_{0.05,(2),6} = 2.492$, $0.01<P<0.05$). It should be noted however that the Dry-Weathered and Rehydrated-Weathered groups had a low number of long bone specimens ($n = 3$ and $n = 5$, respectively), therefore these observations may be due to sampling error.

FIG. 21—*Mean Number of Fracture Fragments*

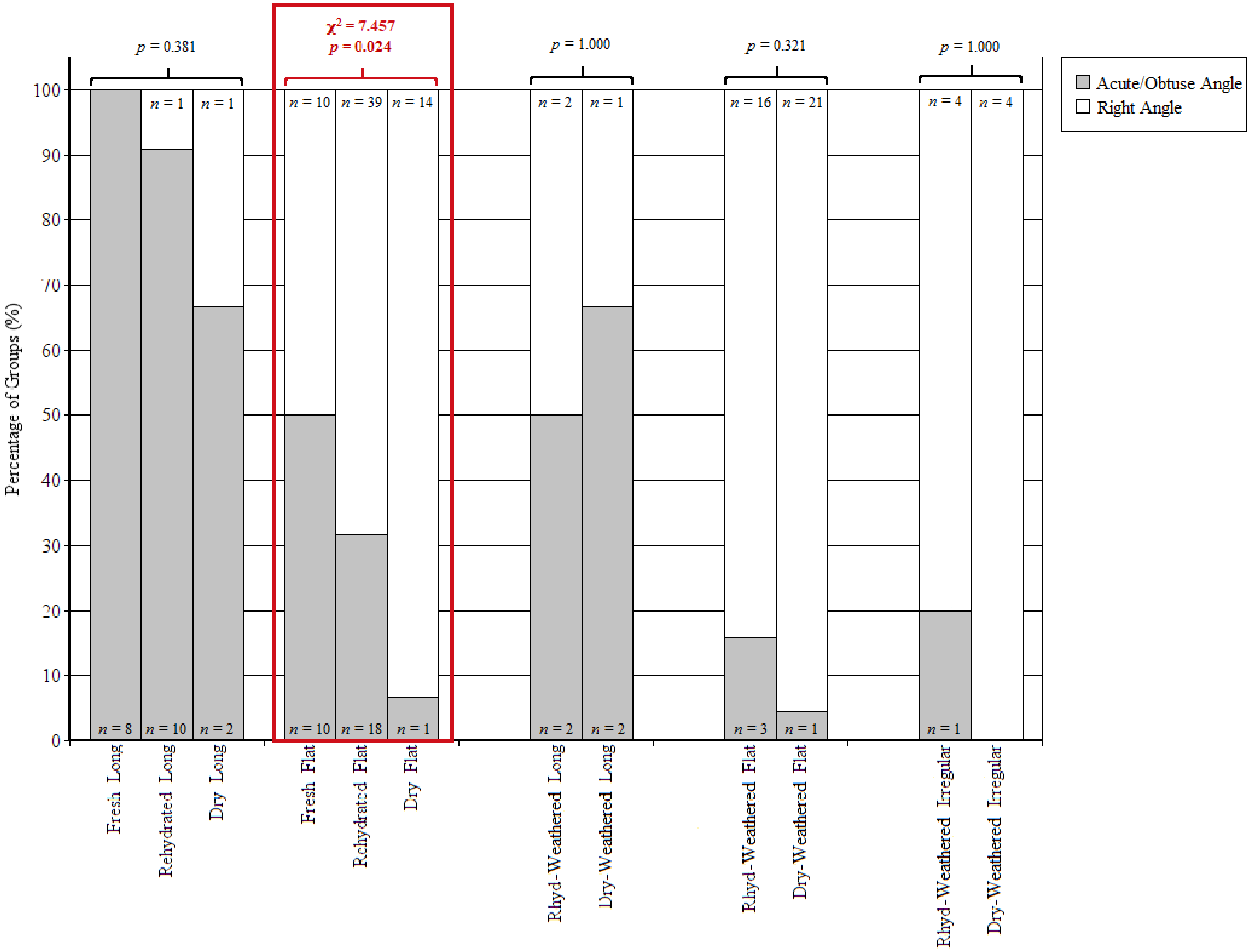


*Red box indicates a significant difference ($p < 0.05$).

2. *Fracture Angle*

The proportions of the subgroups that exhibited acute/obtuse angled fracture angles and perpendicular (or right-angled) fracture angles are summarised in Fig. 22. It should be noted that some of the fracture angles of some of the elements could not be evaluated due to incomplete fracturing or a lack of a visible cortical surface. The Fresh flat bones were found to have a significantly higher proportion of angled fractures (50.00%) and a significantly lower proportion of perpendicular fractures (50.00%) than the Dry-Control flat bones (6.67% and 93.33%, respectively; $\chi^2_{0.05,(2),2} = 7.457$, $0.01<P<0.05$).

FIG. 22—*Fracture Angle*

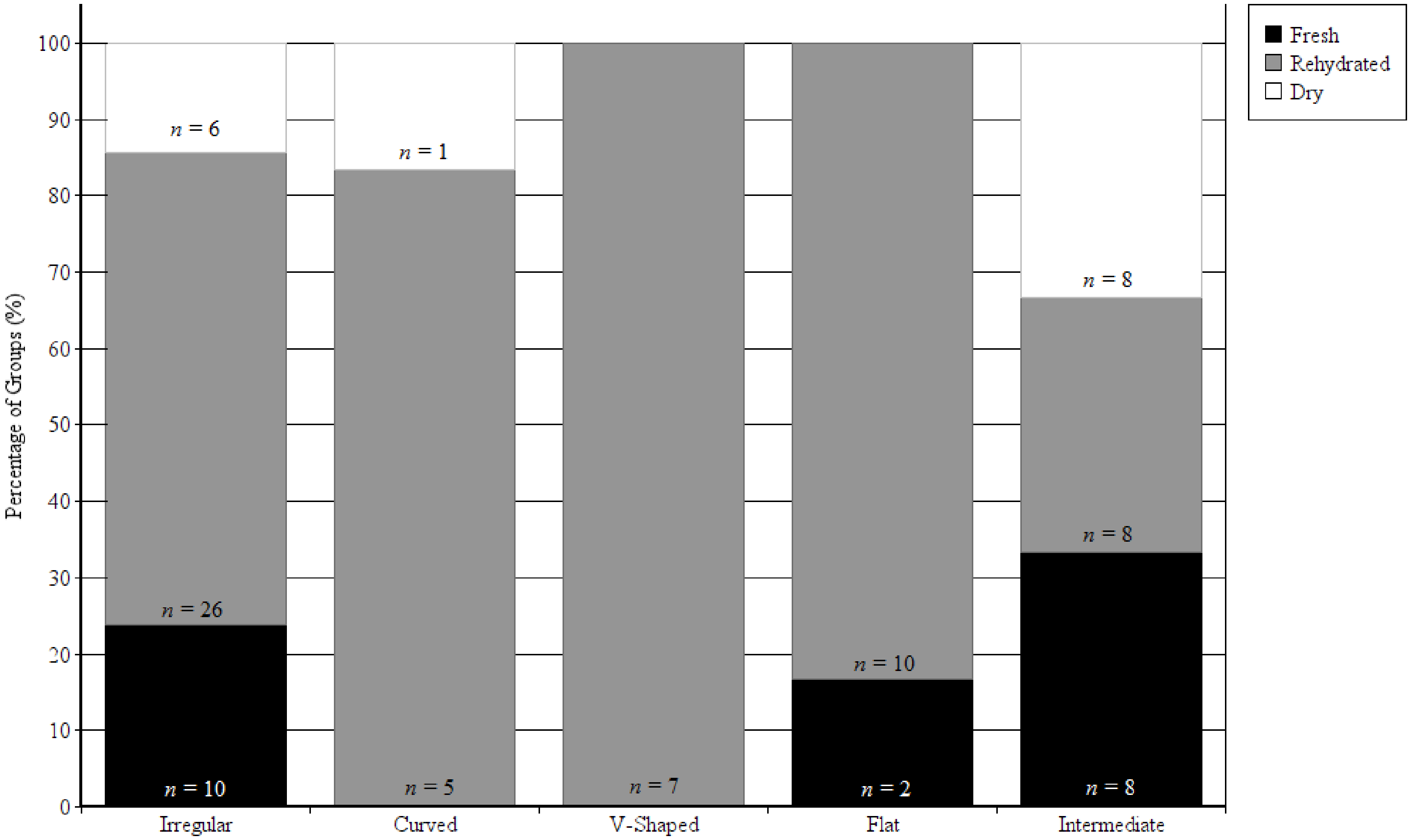


*Red box indicates a significant association ($p < 0.05$).

3. Margin Outline

Using Fisher's Exact Test, no significant association between moisture content and fracture margin was found among the Fresh, Rehydrated, and Dry-Control long bones (p = 0.075). However, among the Fresh, Rehydrated, and Dry-Control flat bones (Fig. 23), the association between moisture content and fracture margin was statistically significant (p = 0.022). The Rehydrated flat bones exhibited higher proportions in the curved (83.33%; n = 5), V-Shaped (100%; n = 7), and flat (83.33%; n = 10) margin outline categories than the Fresh and Dry-

FIG. 23—*Percentage of Flat Bones in Each Moisture Category Exhibiting Various Fracture Margin Outlines*



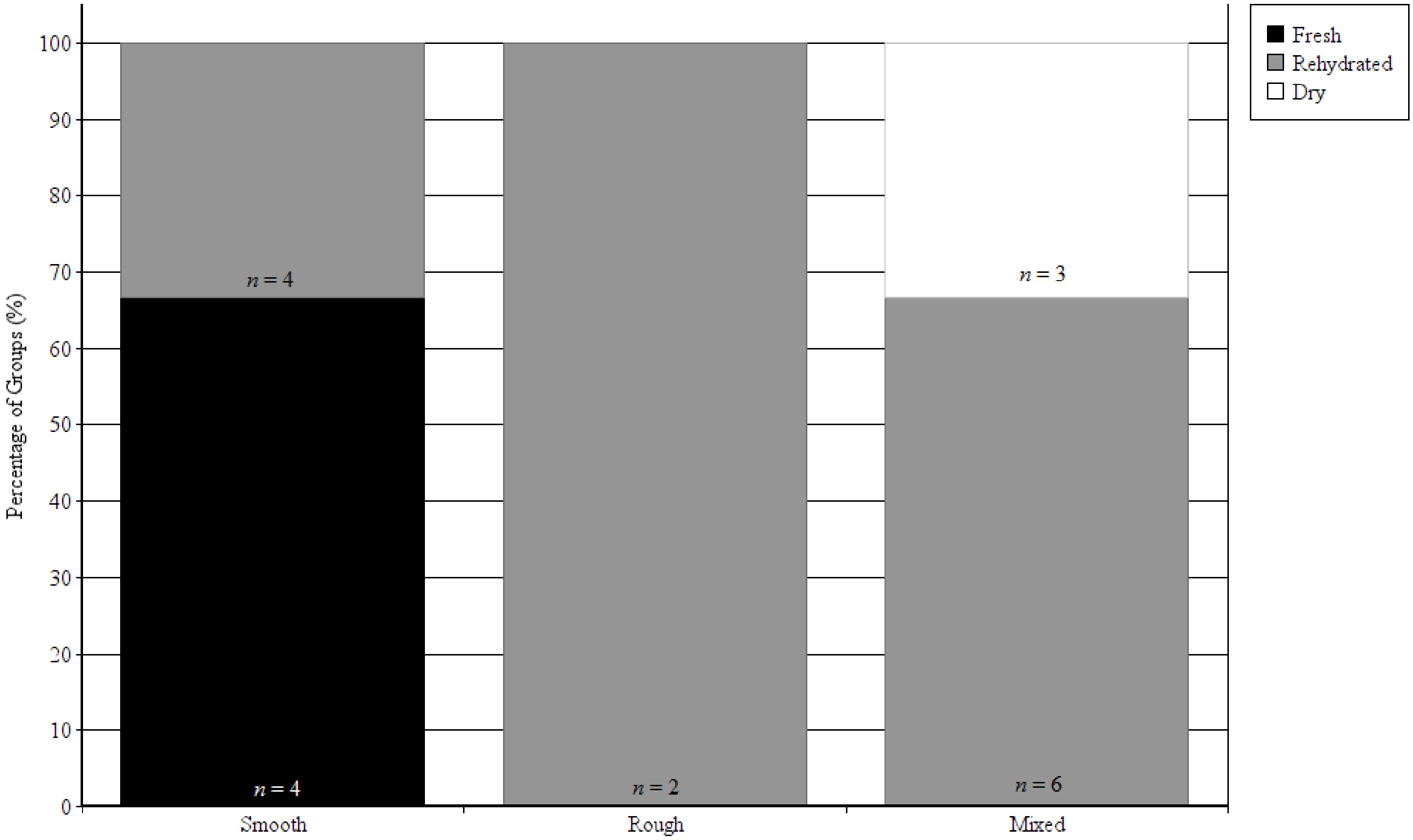
Control flat bones. No half-butterfly margin outlines were observed among the flat bones in any of the moisture categories.

No association between moisture content and fracture margin outline was found in the weathered long bones (p = 0.257) or the weathered flat bones (p = 0.468). Fracture margin morphology was difficult to diagnose in the irregular elements due to a high rate of crushing. All of the Dry-Weathered irregular elements were too highly fragmented to confidently identify their fracture margin outlines, therefore statistical analyses could not be carried out on this subgroup.

4. Fracture Surface Texture

Using Fisher's Exact Test, a significant association between moisture content and fracture surface texture was found in the Fresh, Rehydrated, and Dry-Control long bones (p = 0.002) (Fig. 24). All of the Fresh long bones (n = 8) exhibited smooth fracture surfaces while all of the

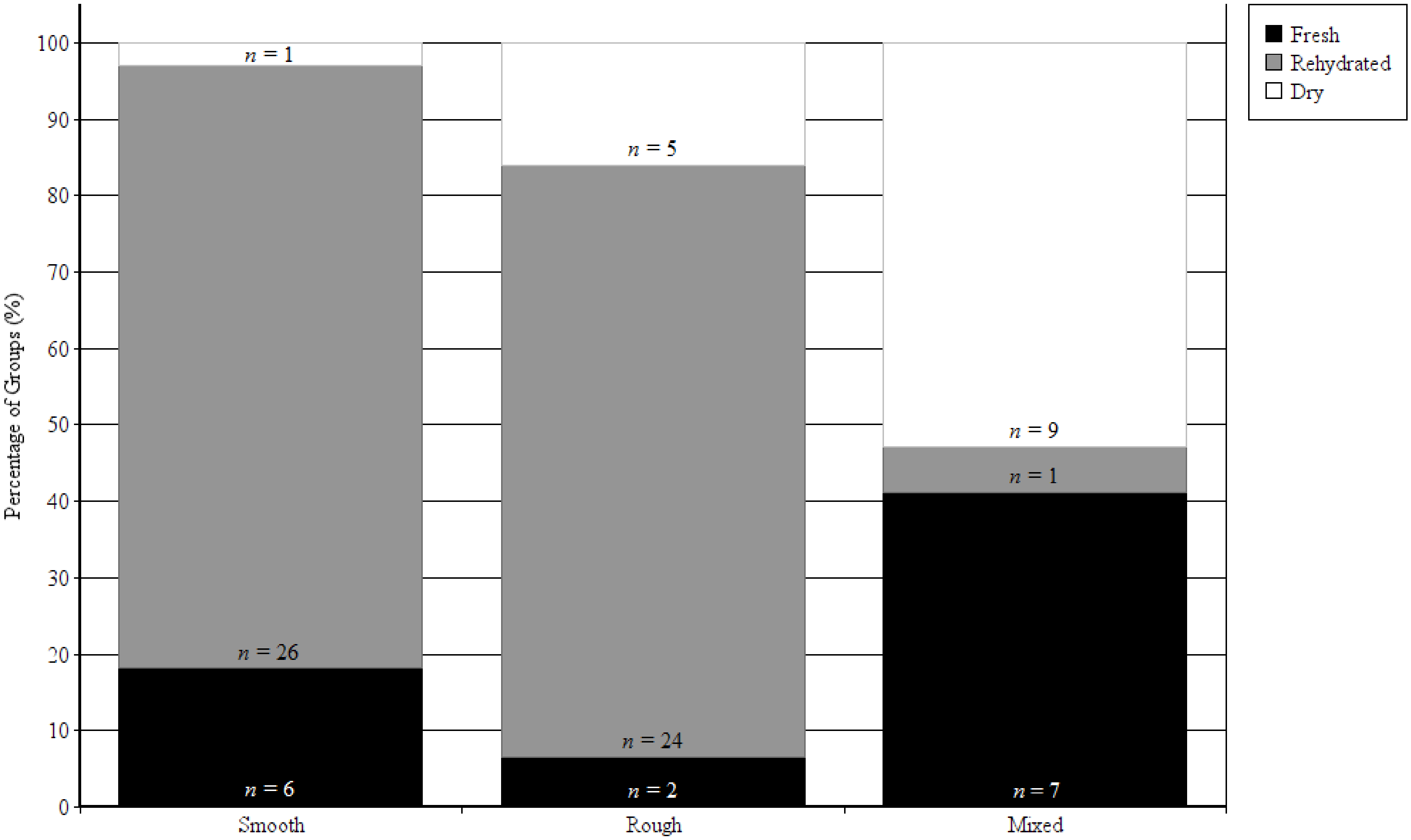
FIG. 24—*Long Bone Fracture Surface Texture*



Dry-Control long bones (n = 3) exhibited mixed-texture surfaces. The Rehydrated long bones, however, exhibited all three surface texture types.

The flat bones also exhibited a statistically significant association between moisture content and fracture surface texture ($p < 0.001$) (Fig. 25). The smooth and rough surface categories exhibited higher proportions of Rehydrated flat bones (78.79%; n = 26 and 77.42%; n = 24, respectively). Expectedly, the rough surface category exhibited a lower proportion of Fresh flat bones (6.45%; n = 2) and the smooth surface category exhibited a lower proportion of Dry-Control flat bones (3.03%; n = 6). The mixed surface category, however, exhibited higher proportions of Fresh and Dry-Control flat bones (41.18%; n = 7 and 52.94%; n = 9, respectively), despite the Rehydrated flat bone group's much larger sample size. No association between moisture content and fracture surface texture was found in the weathered long bones (p = 1.000), flat bones (p = 0.400), or irregular bones (p = 1.000).

FIG. 25—*Flat Bone Fracture Surface Texture*

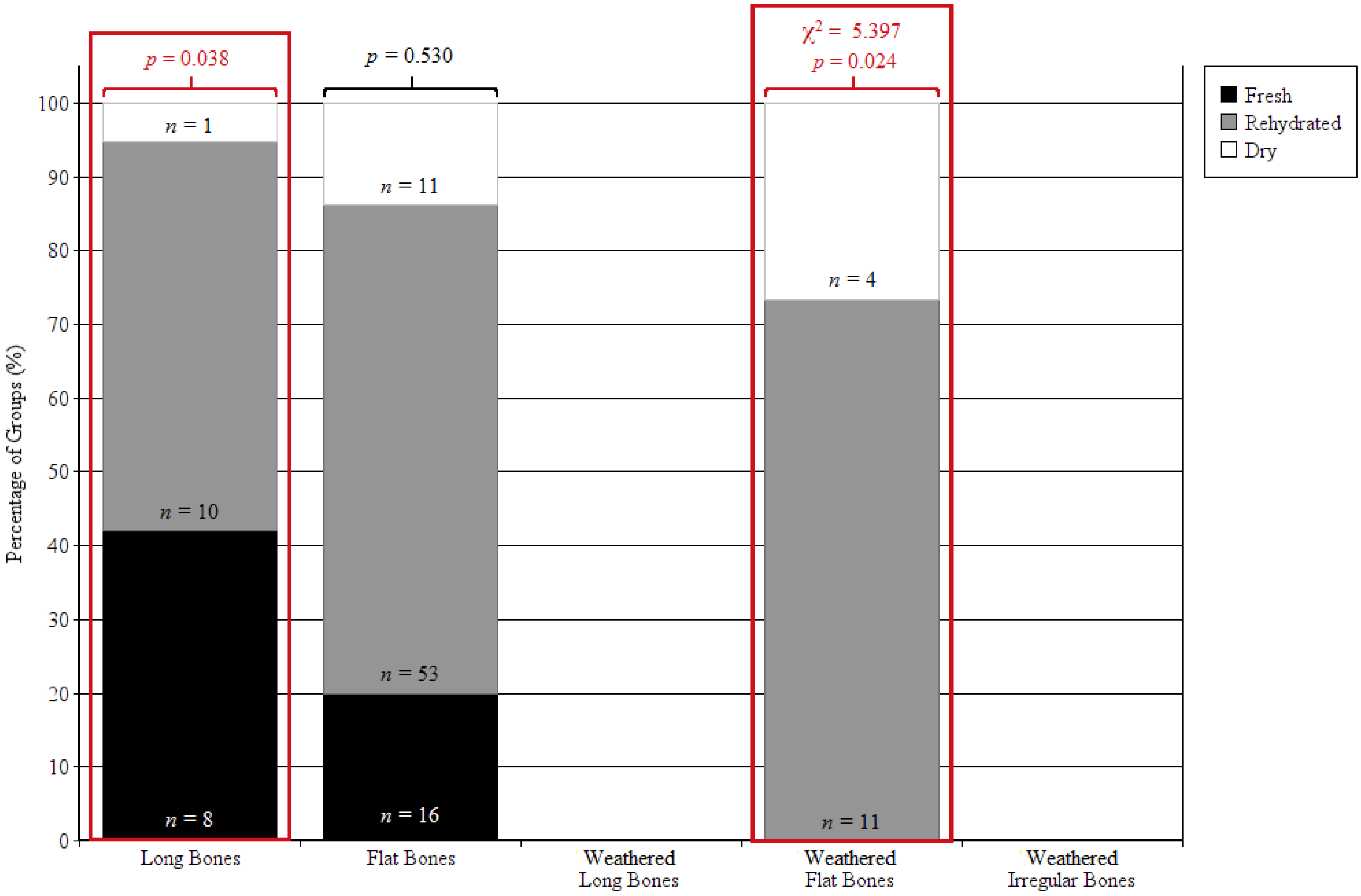


5. Radiating Fracture Lines

The proportions of the groups that exhibited radiating fracture lines can be found in Fig. 26. Fisher's Exact Test found a significant association between moisture content and the propagation of radiating fracture lines in the long bones (p = 0.038), with a significantly higher proportion of radiating fracture lines appearing on Fresh and Rehydrated long bones (42.11% and 52.63%, respectively) than the Dry-Control long bones (5.26%; n = 1). Additionally, among the long bones that exhibited radiating fracture lines, most of the Rehydrated (31.58%; n = 6) and Fresh elements (36.84%; n = 7) had fracture lines that terminated at or near the epiphyses, while the Dry-Control long bone terminated on the diaphysis (n = 1). However, this association was not statistically significant (p = 0.038) due to the small number of sample elements. In the weathered groups, radiating fracture lines were only observed on the flat elements. A significant association was found between moisture content and the presence of radiating fracture lines

($\chi^2_{0.05,(2),1}$ = 5.397, 0.01<P<0.05), with a much higher proportion of Rehydrated-Weathered flat bones exhibiting fracture lines (73.33%; n = 11) than the Dry-Weathered flat bones (26.67%; n = 4).

FIG. 26—*Presence of radiating fracture lines*



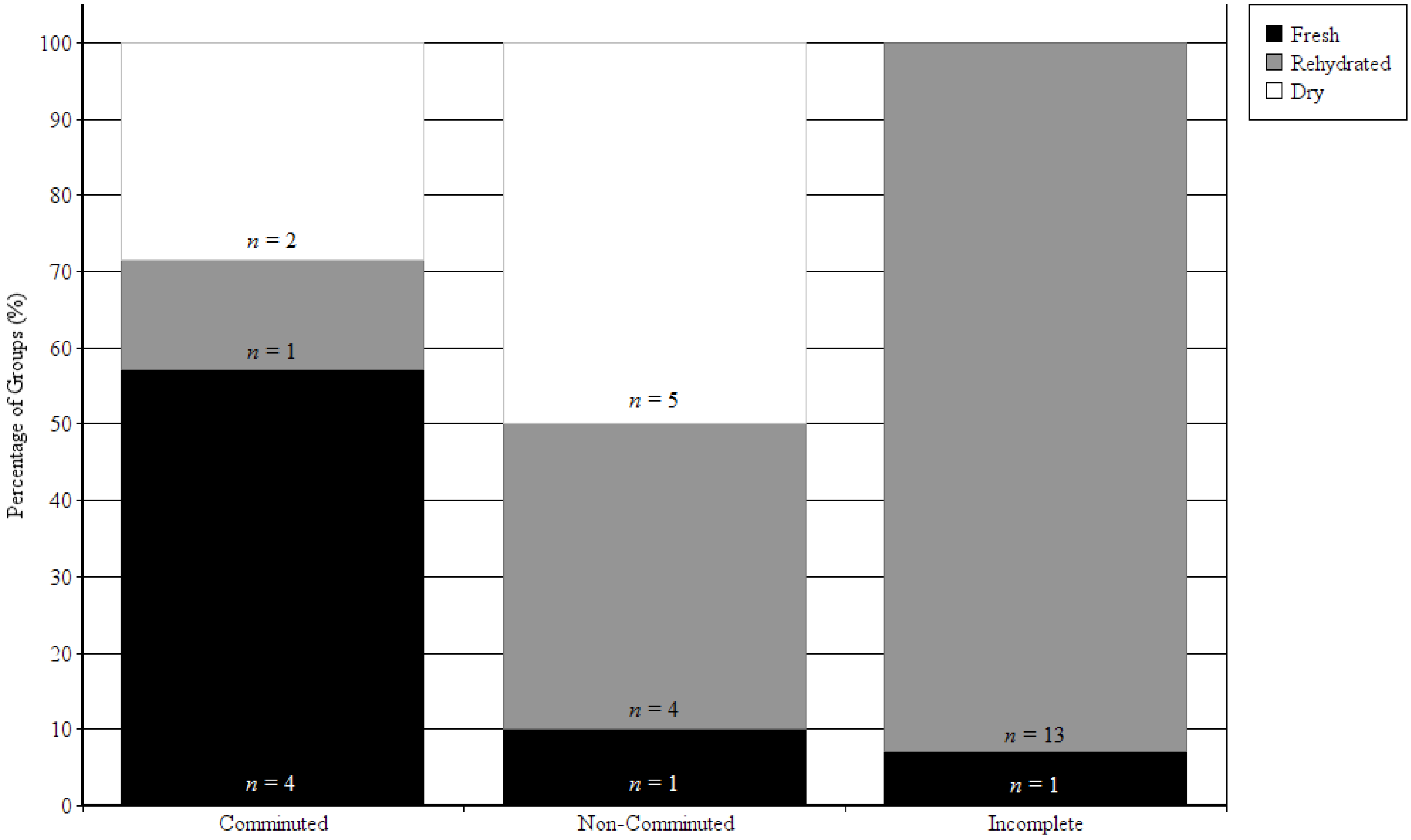
*Red box indicates a significant association ($p < 0.05$).

6. Fracture Classifications

Using Fisher's Exact Test, no significant association between moisture content and fracture classification was found for the cranial elements (p = 0.143) or the long bones (p = 0.138).

The association between moisture content and fracture classification on the flat elements (mandibles, scapulae, and ossa coxae) was statistically significant ($p < 0.001$) (Fig. 27). There was a substantially higher proportion of Fresh flat elements in the comminuted fracture category (57.14%; n = 4), while the non-comminuted fracture category consisted primarily of Rehydrated

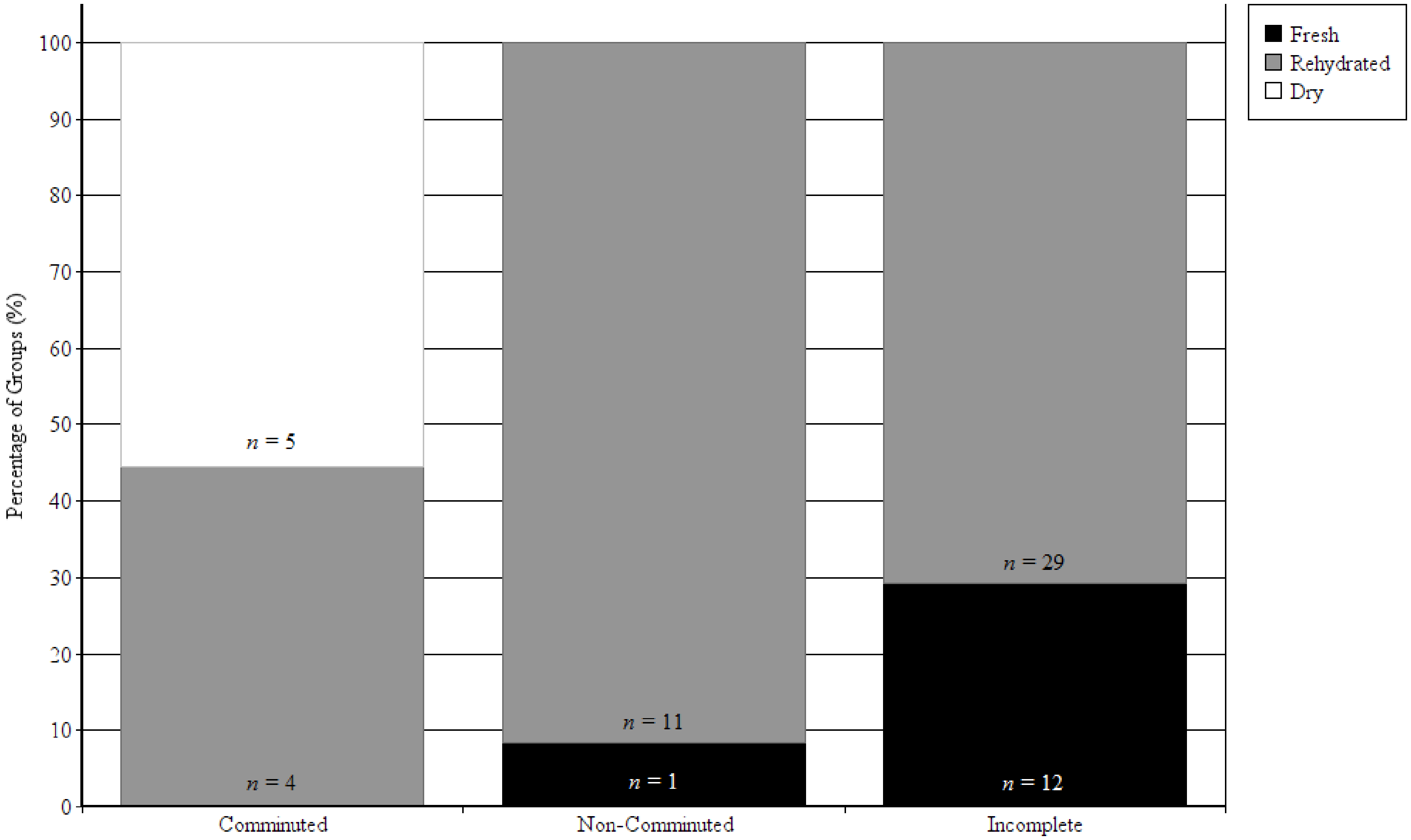
FIG. 27—*Mandibles, scapulae, and ossa coxa fracture classifications*



(50.00%; *n* = 5) and Dry-Control (40.00%, *n* = 4) elements. Finally, the incomplete fracture category consisted primarily of Rehydrated elements (92.86%; *n* = 13). It should be noted however that the Fresh flat elements consisted of mandibles only, and therefore the distribution of fracture classifications for this group may be misrepresented.

The association between moisture content and fracture classification among the ribs was statistically significant ($p < 0.001$) (Fig. 28). All of the Dry-Control ribs exhibited comminuted fractures (*n* = 5). The non-comminuted fracture category consisted primarily of Rehydrated ribs (91.67%; *n* = 11), while the incomplete fracture category consisted of Fresh and Rehydrated ribs (29.27%; *n* = 12 and 70.73%; *n* = 29, respectively).

FIG. 28—*Rib Fracture Classifications*



Additional Observations

In addition to the six primary traits that were evaluated in each of the sample groups, three additional "secondary" traits were noted among Fresh and Rehydrated groups – peeling at the Fresh bone fracture margins, longitudinal splitting in Fresh and Rehydrated rib fractures, and "tearing" fractures among the Rehydrated flat bones.

Peeling or flaking of the periosteal membrane at the fracture margins is a trait typically observed in fresh bone (perimortem) trauma (Fig. 29) (1,30). This trait was observed in 36.67% of the Fresh elements, but was not observed in any other group. Fracture peeling was observed in 37.50% (*n* = 3) of the Fresh long bones and 36.36% (*n* = 11) of the Fresh flat bones.

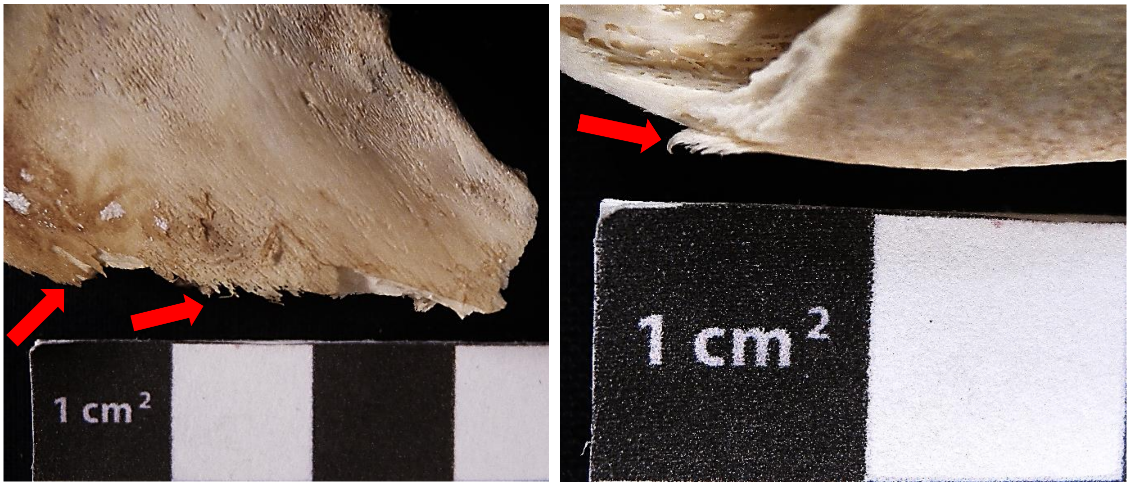


FIG. 29—*Peeling of the fracture margins (Fresh mandibles). Photos by author.*

The Fresh and Rehydrated ribs demonstrated a tendency to split along the superior and inferior borders near the point of impact, with some splits extending nearly the full length of the body (Fig. 30). This longitudinal splitting was observed in 53.85% (*n* = 7) of the Fresh ribs and 45.45% (*n* = 20) of the Rehydrated ribs. The difference in these frequencies was not statistically significant ($\chi^2_{0.05,(2),1} = 0.283$; $0.10<P<1.000$). This trait was particularly more common in ribs that exhibited incomplete fractures.

FIG. 30—*Longitudinal splitting at superior and inferior borders of ribs (TOP: Fresh rib; BOTTOM: Rehydrated rib). Photos by author.*

A final secondary trait unique to the Rehydrated flat bone fractures was the phenomenon of ripping or "tearing" fractures and fracture lines. These types of fractures were usually the result of secondary forces produced by the support platforms of the bone fracture apparatus, which worked in opposition to the primary force of the fracture mechanism as it struck the bone. This sometimes resulted in secondary fractures. Among the waterlogged flat bones of the Rehydrated group, however, the result was analogous to ripping wet newspaper, with ragged or fringed separations and typically straight or stepped outlines (Fig. 31). When viewed under a microscope, these "tear fractures" exhibited a jagged, almost jigsaw-like appearance, which was distinguishable from rough, relatively flat secondary fractures observed on the Fresh bones (Fig. 32). This trait was observable in 50.77% (*n* = 33) of the Rehydrated flat bones. It was visible on all of the cranial (*n* = 3) and scapular (*n* = 9) elements, as well as most of the mandibles (80.00%; *n* = 4) and ossa coxae (75.00%; *n* = 3). This trait was much less common on the ribs, where it was visible on only 31.82% (*n* = 14) of the elements.

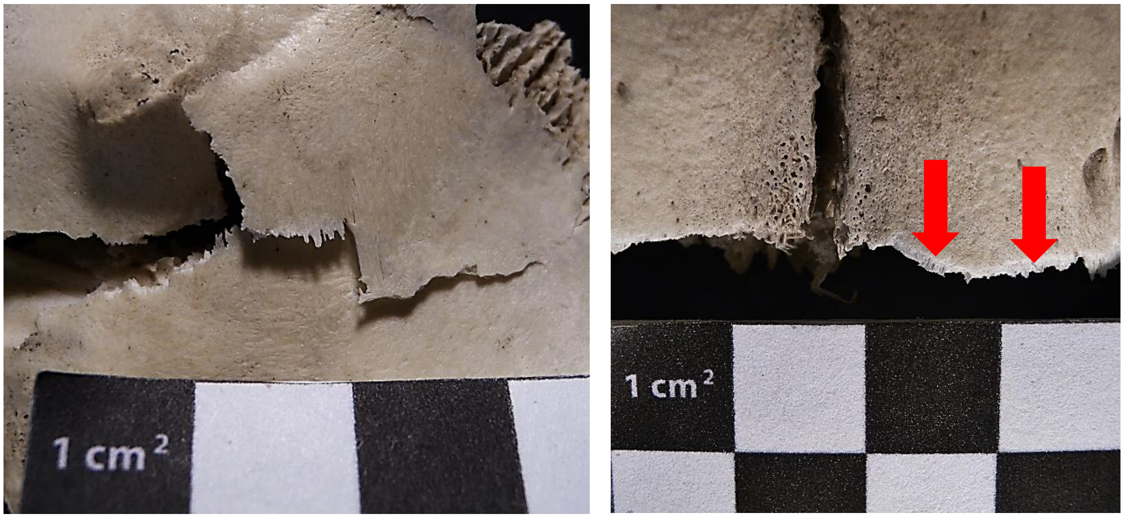


FIG. 31—*Rehydrated bone tearing (Rehydrated maxilla; Rehydrated parietals). Photos by author.*

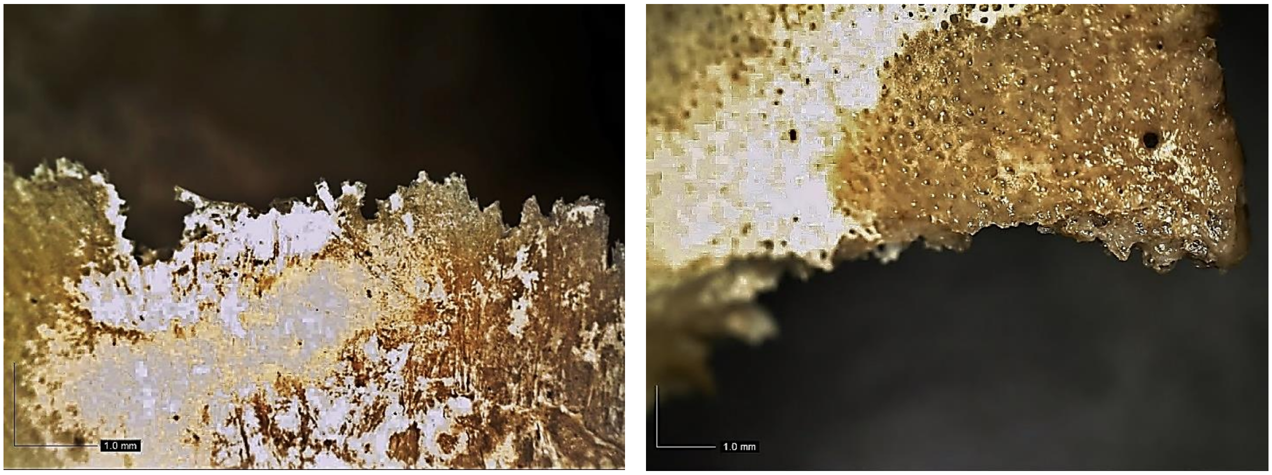


FIG. 32—*Secondary fracture of a Rehydrated cranium (left, 55× magnification) compared to secondary fracture of a Fresh cranium (right, 40× magnification). Note the fringed, jagged, almost jig-saw-like appearance of the torn edge of the Rehydrated bone compared to rough, relatively flat appearance of the Fresh bone. Photos by author.*

Discussion

The results of this experiment revealed some interesting trends as well as a number of deviations among fresh, dry, and rehydrated bone fracture morphology. As the level of water saturation in each of the rehydrated groups did not differ significantly, it may be inferred that variations in fracture morphology patterns were not caused by variations in water content between the rehydrated groups, but rather by intrinsic factors such as structure and composition.

For most of the fracture traits, there was no association between moisture content and fracture morphology in the long bones. The exceptions were the appearance of the fracture surface texture ($p = 0.002$) and the propagation of radiating fracture lines. In this experiment, Fresh long bones appeared more likely to exhibit smooth fracture surfaces (100%; $n = 8$) while Dry-Control long bones were more likely to exhibit mixed-texture fracture surfaces (100%; $n = 3$). Rehydrated long bones, by contrast, exhibited smooth ($n = 4$), rough ($n = 2$), and mixed-texture surfaces ($n = 6$). Radiating fracture lines were also more likely to appear on Fresh and Rehydrated long bones (42.11%; $n = 8$ and 52.63%; $n = 10$, respectively; $p = 0.038$). The Dry-Control long bones, however, seemed less likely to exhibit this trait (5.26%; $n = 1$).

Rehydration appeared to have the greatest influence on the flat bones, with significant associations existing between moisture content and most of the fracture traits. Rehydrated flat bones were more likely to produce fewer fracture fragments ($\bar{X} = 1.77$; $n = 65$; $t_{0.05,(2),15} = -3.140$, $0.001<P<0.01$) and fewer perpendicular fracture angles (50.00%; $n = 10$; $\chi^2_{0.05,(2),2} = 7.457$, $0.01<P<0.05$) than the Dry-Control flat bones ($\bar{X} = 5.07$; $n = 15$ and 93.33%; $n = 14$, respectively). The Rehydrated flat bones also exhibited higher proportions in the curved (83.33%; $n = 5$), V-Shaped (100%; $n = 7$), and flat (83.33%; $n = 10$) margin outline categories than the Fresh and Dry-Control flat bones. Furthermore, the smooth and rough surface texture categories exhibited higher proportions of Rehydrated flat bones (78.79%; $n = 26$ and 77.42%; $n = 24$, respectively), while the mixed surface texture category exhibited a much lower proportion of Rehydrated flat bones (5.88%; $n = 1$). The only trait for which the flat bones did not exhibit any significant association with moisture content was the appearance of radiating fracture lines near the point of impact.

Among the weathered groups, there was no association between moisture content and fracture morphology for most of the fracture traits. One exception was that the Rehydrated-Weathered long bones exhibited a significantly higher average number of fracture fragments ($\bar{X}$ = 10.00; *n* = 3) than the Dry-Weathered long bones ($\bar{X}$ = 3.67; *n* = 5; $t_{0.05,(2),6}$ = 2.492, 0.01<P<0.05) – however, due to the small sample size for these groups, this observation may not be representative of a larger population. Another exception was that the Rehydrated-Weathered flat bones exhibited a significantly higher proportion of radiating fracture lines (57.89%; *n* = 11; $\chi^2_{0.05,(2),1}$ = 5.397, 0.01<P<0.05) near the point of impact than the Dry-Weathered flat bones (21.05%; *n* = 4).

With regards to fracture classifications, a significant association with moisture content was found for the mandibles, scapulae, and ossa coxae ($p < 0.001$), with the incomplete fracture category consisting primarily of Rehydrated elements (92.86%; *n* = 13). However, the Fresh elements of this group consisted of mandibles only, and therefore the distribution of fracture classifications may be misrepresented. The ribs also exhibited a significant association between moisture content and fracture classification ($p < 0.001$), with the incomplete fracture category exhibiting higher proportions in Fresh and Rehydrated ribs (29.27%; *n* = 12 and 70.73%; *n* = 29, respectively) while the dry ribs exhibited comminuted fractures only (*n* = 5).

The Dry-Control groups exhibited some deviation from typical postmortem fracture morphology for many of the fracture traits. For instance, the flat dry bones exhibited a higher proportion of irregular and intermediate fracture margins, yet they did not exhibit any flat margins, which are normally associated with postmortem trauma. The dry long and flat bones both exhibited high proportions of mixed-textured fracture surfaces – an outline that may be conceptualised as a transitional phase between the (typically perimortem) smooth surface and the (typically postmortem) rough surface.

The tendency of the Dry-Control sample group to exhibit a mix of both “fresh” and “dry” fracture traits suggests that most of these bones have probably retained their organic components. Collagen fibres have the greatest influence over the biomechanical behaviour of bones, primarily contributing to the strength of the bone and its ability to absorb stress (5,7,13,17). For example, Wang and his associates (2001) conducted an experimental study in which they demonstrated that bones with a higher amount of denatured collagen experienced reduced the strength and required less work to fracture (13). It is very likely that the collagen fibres within the Dry-Control and Rehydrated sample elements have remained intact, though they have grown brittle due to lack of moisture. Therefore, these bones exist on a spectrum somewhere between the perimortem and the postmortem interval, causing them to exhibit both fresh and dry bone fracture morphologies.

Moisture content is another critical component of a bone's structure that greatly influences its biomechanical behaviour (15,19,20,42). The fibrils of the collagen fibres themselves are surrounded by a gelatinous extracellular matrix that is composed primarily of water (17,19). In living and recently-deceased bones, collagen tends to retain its flexibility due to the high moisture content within the skeletal material (3,5). Bones that are fresh and hydrated are typically more ductile while dry bones are stiffer and more brittle (5,10,15,17,20,42). As a result, fresh and dry bones react differently to stress, however the interval during which bones will exhibit fresh fracture traits is confounded by the gradual and variable process of moisture loss following death (2,5,7,17,20,30).

As bones become dehydrated, their stiffness and hardness increases while their elasticity, and with it the amount of energy required to produce a fracture, decreases (10,15,19,20). This gradual decrease in elasticity can be attributed to water's role as a stabilising matrix surrounding collagen fibrils (19). As the moisture within the bone disappears, the bone will eventually lose its elasticity and thus will not be able to withstand as much strain, causing it to fracture under less force than a hydrated bone (3,20). Given this information, it can be inferred that the moisture content of a bone and its distribution within the skeletal tissue influence its biomechanical response to traumatic events (10,15). In this experiment, it was most likely that the rehydration of the preserved collagen fibres within the dry bones resulted in the restoration of the bones' fresh qualities, such as flexibility and strength. The outcome of this led to the rehydrated bone fractures sharing some traits in common with the fresh bones – particularly in the number of fracture fragments produced, radiating fracture lines in the long bones, and fracture angles and incomplete fractures in the flat bones.

Furthermore, among the weathered sample groups there were very few significant differences between the fracture morphologies of the dry and rehydrated elements. Due to the highly degraded nature of these bones, it is unlikely that much collagen has been preserved, thus rehydration would have little impact on their fracture morphology. This lends support to the conclusion that the effect of moisture content on the formation of skeletal fractures is dependent upon the degree of preservation of a bone's organic components.

Conclusion

Understanding the mechanisms that shape how fractures are produced on skeletal material is essential for forensic anthropologists and bioarchaeologists to distinguish between perimortem and postmortem trauma. Perimortem skeletal trauma is often conceptualised as damage that occurs on bones that are still fresh, normally taking place at or near an organism's time of death. It can be distinguished from postmortem trauma, which takes place on bones that are dry and have lost most of their organic components, and is usually associated with taphonomic processes. Failure to correctly interpret when and how skeletal fractures took place can have serious consequences in a forensic investigation, such misleading investigators and even wrongful convictions (8,10,20). Therefore, future research should be devoted to understanding the biomechanics of bone trauma and the changes skeletal material experiences as it decomposes.

The complication with these two phases of bone death is the significant degree of overlap between them, as skeletal material makes a gradual transition to a dry state following the death of the organism (2,3,5,7,17,30). Depending on the depositional environment, bones may retain their moisture and collagen matrix long after death, which in turn extends the interval during which damage to the bone will produce fractures that exhibit typically perimortem traits (1,7,9,10,30). This study demonstrated that the introduction of moisture to dried bones can have a restorative effect on the biomechanical nature of skeletal material, provided at least some of the bone's organic properties have remained intact. When sheep bones that had been contained within a controlled environment for 20 years were rehydrated, the preserved organic components within the bones regained many of their fresh qualities, which in turn altered the biomechanical response of these elements to external forces. The resulting fractures of these rehydrated remains exhibited traits in common with both their fresh and dehydrated counterparts. In particular, the rehydrated flat bones (mandibles, scapulae, ossa coxae, and ribs) exhibited significantly more incomplete fractures than dry flat bones, which were more likely to exhibit complete fractures. These observations call attention to the problem of distinguishing between perimortem and postmortem trauma, especially among elements that may have been exposed to moisture-rich environments.

Two unique traits were identified that may be used to distinguish between fresh and rehydrated fractures. The first was the peeling of the periosteal membrane at the fracture margins – a trait that occurred exclusively on the fresh elements and was observed on roughly a third of the fresh sample group. However, the usefulness of this trait may be limited. The thin periosteal membrane typically wears away rapidly when a bone is exposed to environmental elements. This trait would not be observable in cases involving older remains. The second unique trait that was identified was the appearance of tear-like secondary fractures on the rehydrated flat bones. This feature was observed on roughly half of the rehydrated flat elements and was not observed in any other sample group. These unique features may be helpful in identifying fresh or rehydrated fractures on skeletons with traumatic injuries, however, these identifiers are only useful when they are present – their absence should not be taken as an indicator that a bone was not wet when a fracture in question took place.

There are a number of limitations with this experiment. First, the small sample size of several subgroups (particularly among the long bones and the irregular bones) makes the validity of the statistical tests unclear. Now that an association between moisture content and fracture morphology has been identified among the flat bone groups, future studies should include much larger samples to determine if this association is truly statistically significant. There is also the issue of the transferability of data obtained from nonhuman models. Different vertebrate species have different bone compositions, and therefore caution should be exercised when generalising results found on nonhuman models to human examples. Furthermore, several of the specimens were not fully skeletally mature (the fresh bone group consisted exclusively of immature bone elements). Since subadult bone contains a higher percentage of collagen than adult bone (25), it is unclear to what degree the results may have been influenced by the skeletal maturity of the specimens as opposed to the moisture content in the bones. Future studies should attempt to control for these variables. Other limitations included the use of fragmented weathered samples as opposed to whole samples, the necessity of using an uncontrolled force to fracture the more resilient long bones, and the uncertainty as to the actual collagen content of each of the specimens. These issues may be avoided in future studies by 1) obtaining whole bones in an advanced state of diagenesis, 2) using a laboratory grade controlled fracture machine so that exact forces of impact can be calculated, and 3) taking bone slices from each specimen so that collagen content can be determined.

The results of this exploratory study into the effects of skeletal rehydration on fracture morphology suggest that anthropologists should exercise caution when interpreting trauma on skeletal remains – especially remains that may have been exposed to moisture at some point after death. As a bone's structure and composition is gradually modified after death by taphonomic processes such as weathering, there is no distinct boundary between the perimortem and the postmortem interval (2,3,16,20). To complicate matters further, bone degradation is dependent on a broad array of factors both intrinsic and extrinsic, making decompositional processes extremely difficult to predict (20,24). It has been suggested by some authors that this problem may be mitigated by reconceptualising the perimortem and postmortem intervals as a continuum of "fresh" and "dry" bones, rather than as mutually exclusive categories (7,9,20,21). In other words, instead of classifying skeletal trauma in relation to the death event, anthropologists should describe bone fractures with regards to the physical state of the bones at the time of the traumatic event and within the context of the depositional environment. This requires the anthropologist to have a comprehensive understanding of the depositional environment and to consider the extent to which skeletal remains may have been exposed to moisture.

The results of this study seem to indicate that the highest degree of caution should be exercised when interpreting trauma on flat bones, as fracture morphology in this group was most affected by rehydration. The presence of "tear fractures" on these bones may be helpful in distinguishing rehydrated fractures from fresh fractures. Future research on this topic should focus on the tear fracture as a potential diagnostic trait. Larger, more representative samples will also increase the validity of the results and provide a clearer picture as to what kinds of bones are most are most affected by rehydration and which fracture traits are most reliable for trauma analysis. Understanding the ways moisture can alter the biomechanics of bones will lead to more accurate interpretations of trauma and mitigate the risks of incorrectly associating wet bone fractures with death events.

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Appendix A

Listed below are the raw data collected for mass and water content from the specimens in each sample group.

Mass and Water Content							
Specimen	*Group*	*Element*	*Maturity*	*Species*	*Mass*$_1$ *(g)*	*Mass*$_2$ *(g)*	*Water Content (%)*
AK-R01a	Rehydrated	Cranium: parietals, occipital, temporals	Adult	Ovine	166	208	25%
AK-R01b	Rehydrated	Cranium: maxilla, zygomatic	Adult	Ovine	166	208	25%
AK-R01c	Rehydrated	Cranium: maxilla, zygomatic	Adult	Ovine	166	208	25%
AK-R02	Rehydrated	Mandible	Adult	Ovine	37	41	11%
AK-R03	Rehydrated	Mandible	Adult	Ovine	58	64	10%
AK-R04	Rehydrated	Mandible	Adult	Ovine	50	55	10%
AK-R05	Rehydrated	Mandible	Adult	Ovine	41	46	12%
AK-R06	Rehydrated	Mandible	Subadult	Ovine	27	30	11%
AK-R07	Rehydrated	Femur	Adult	Ovine	67	93	39%
AK-R08	Rehydrated	Femur	Subadult	Ovine	32	39	22%
AK-R09	Rehydrated	Femur	Adult	Ovine	51	68	33%
AK-R10	Rehydrated	Femur	Adult	Ovine	63	89	41%
AK-R11	Rehydrated	Humerus	Subadult	Ovine	28	34	21%
AK-R12	Rehydrated	Tibia	Adult	Ovine	44	54	23%
AK-R13	Rehydrated	Humerus	Adult	Ovine	34	46	35%
AK-R14	Rehydrated	Humerus	Adult	Ovine	40	55	38%
AK-R15	Rehydrated	Tibia	Adult	Ovine	54	62	15%
AK-R16	Rehydrated	Tibia	Adult	Ovine	54	67	24%
AK-R17	Rehydrated	Tibia	Subadult	Ovine	29	34	17%
AK-R18	Rehydrated	Os Coxa	Adult	Ovine	115	150	30%
AK-R19	Rehydrated	Os Coxa	Adult	Ovine	113	144	27%
AK-R20	Rehydrated	Os Coxa	Subadult	Ovine	39	48	23%
AK-R21	Rehydrated	Os Coxa	Subadult	Ovine	41	58	41%
AK-R22	Rehydrated	Scapula	Adult	Ovine	97	121	25%
AK-R23	Rehydrated	Scapula	Adult	Ovine	27	35	30%
AK-R24	Rehydrated	Scapula	Adult	Ovine	98	120	22%
AK-R25	Rehydrated	Scapula	Adult	Ovine	26	35	35%
AK-R26	Rehydrated	Scapula	Adult	Ovine	32	39	22%
AK-R27	Rehydrated	Scapula	Adult	Ovine	28	35	25%
AK-R28	Rehydrated	Scapula	Adult	Ovine	21	33	57%
AK-R29	Rehydrated	Scapula	Subadult	Ovine	12	18	50%
AK-R30	Rehydrated	Scapula	Adult	Ovine	31	43	39%
AK-R31	Rehydrated	Rib	Adult	Ovine	9	12	33%
AK-R32	Rehydrated	Rib	Adult	Ovine	7	11	57%
AK-R33	Rehydrated	Rib	Subadult	Ovine	8	10	25%
AK-R34	Rehydrated	Rib	Adult	Ovine	14	18	29%
AK-R35	Rehydrated	Rib	Subadult	Ovine	7	10	43%
AK-R36	Rehydrated	Rib	Adult	Ovine	8	12	50%
AK-R37	Rehydrated	Rib	Adult	Ovine	6	8	33%
AK-R38	Rehydrated	Rib	Adult	Ovine	10	12	20%
AK-R39	Rehydrated	Rib	Adult	Ovine	8	11	38%
AK-R40	Rehydrated	Rib	Subadult	Ovine	13	17	31%
AK-R41	Rehydrated	Rib	Adult	Ovine	5	7	40%
AK-R42	Rehydrated	Rib	Adult	Ovine	6	8	33%
AK-R43	Rehydrated	Rib	Subadult	Ovine	6	8	33%
AK-R44	Rehydrated	Rib	Adult	Ovine	11	15	36%
AK-R45	Rehydrated	Rib	Adult	Ovine	6	9	50%
AK-R46	Rehydrated	Rib	Adult	Ovine	10	14	40%
AK-R47	Rehydrated	Rib	Subadult	Ovine	5	8	60%
AK-R48	Rehydrated	Rib	Subadult	Ovine	4	5	25%
AK-R49	Rehydrated	Rib	Adult	Ovine	10	12	20%
AK-R50	Rehydrated	Rib	Adult	Ovine	8	10	25%
AK-R51	Rehydrated	Rib	Subadult	Ovine	16	19	19%
AK-R52	Rehydrated	Rib	Subadult	Ovine	7	9	29%
AK-R53	Rehydrated	Rib	Subadult	Ovine	4	6	50%
AK-R54	Rehydrated	Rib	Subadult	Ovine	8	9	13%
AK-R55	Rehydrated	Rib	Subadult	Ovine	14	17	21%

Mass and Water Content

Specimen	*Group*	*Element*	*Maturity*	*Species*	*Mass*$_1$ *(g)*	*Mass*$_2$ *(g)*	*Water Content (%)*
AK-R56	Rehydrated	Rib	Adult	Ovine	9	11	22%
AK-R57	Rehydrated	Rib	Subadult	Ovine	14	17	21%
AK-R58	Rehydrated	Rib	Subadult	Ovine	21	27	29%
AK-R59	Rehydrated	Rib	Subadult	Ovine	7	9	29%
AK-R60	Rehydrated	Rib	Subadult	Ovine	8	9	13%
AK-R61	Rehydrated	Rib	Subadult	Ovine	9	12	33%
AK-R62	Rehydrated	Rib	Subadult	Ovine	9	12	33%
AK-R63	Rehydrated	Rib	Subadult	Ovine	6	8	33%
AK-R64	Rehydrated	Rib	Subadult	Ovine	6	9	50%
AK-R65	Rehydrated	Rib	Subadult	Ovine	14	17	21%
AK-R66	Rehydrated	Rib	Subadult	Ovine	8	10	25%
AK-R67	Rehydrated	Rib	Subadult	Ovine	4	4	< 25%
AK-R68	Rehydrated	Rib	Subadult	Ovine	5	6	20%
AK-R69	Rehydrated	Rib	Subadult	Ovine	6	8	33%
AK-R70	Rehydrated	Rib	Subadult	Ovine	8	10	25%
AK-R71	Rehydrated	Rib	Subadult	Ovine	6	7	17%
AK-R72	Rehydrated	Rib	Subadult	Ovine	3	4	33%
AK-R73	Rehydrated	Rib	Subadult	Ovine	6	8	33%
AK-R74	Rehydrated	Rib	Adult	Ovine	6	9	50%
AK-TR01	Rehydrated-Weathered	Cranium	Bovine	Adult	16	21	31%
AK-TR02	Rehydrated-Weathered	Cranium	Bovine	Adult	14	18	29%
AK-TR03	Rehydrated-Weathered	Cranium	Bovine	Adult	3	4	33%
AK-TR04	Rehydrated-Weathered	Cranium	Bovine	Adult	4	6	50%
AK-TR05	Rehydrated-Weathered	Cranium	Bovine	Adult	3	3	0%
AK-TR06	Rehydrated-Weathered	Cranium	Bovine	Adult	4	4	0%
AK-TR07	Rehydrated-Weathered	Mandible	Porcine	Adult	81	97	20%
AK-TR08	Rehydrated-Weathered	Mandible	Bovine	Adult	49	61	24%
AK-TR09	Rehydrated-Weathered	Mandible	Bovine	Adult	20	22	10%
AK-TR10	Rehydrated-Weathered	Mandible	Bovine	Adult	27	30	11%
AK-TR11	Rehydrated-Weathered	Mandible	Bovine	Adult	13	15	15%
AK-TR12	Rehydrated-Weathered	Mandible	Bovine	Adult	9	10	11%
AK-TR13	Rehydrated-Weathered	Mandible	Bovine	Adult	5	6	20%
AK-TR14	Rehydrated-Weathered	Os Coxa	Bovine	Adult	9	13	44%
AK-TR15	Rehydrated-Weathered	Os Coxa	Bovine	Adult	10	14	40%
AK-TR16	Rehydrated-Weathered	Os Coxa	Bovine	Adult	4	6	50%
AK-TR17	Rehydrated-Weathered	Flat Fragment	Unknown	Unknown	5	7	40%
AK-TR18	Rehydrated-Weathered	Os Coxa	Unknown	Unknown	4	6	50%
AK-TR19	Rehydrated-Weathered	Long Fragment	Unknown	Unknown	3	4	33%
AK-TR20	Rehydrated-Weathered	Long Fragment	Unknown	Unknown	3	4	33%
AK-TR21	Rehydrated-Weathered	Tibia	Unknown	Subadult	6	9	50%
AK-TR22	Rehydrated-Weathered	Phalanx	Unknown	Unknown	4	4	0%
AK-TR23	Rehydrated-Weathered	Long Epiphysis (Irregular)	Unknown	Subadult	6	9	50%
AK-TR24	Rehydrated-Weathered	Irregular Fragment	Unknown	Subadult	6	7	17%
AK-TR25	Rehydrated-Weathered	Irregular Fragment	Unknown	Unknown	2	3	50%
AK-TR26	Rehydrated-Weathered	Long Fragment	Unknown	Unknown	7	10	43%
AK-TR27	Rehydrated-Weathered	Caudal Vertebra (Irregular)	Unknown	Unknown	2	3	50%
AK-TR28	Rehydrated-Weathered	Long Fragment	Unknown	Unknown	4	4	0%
AK-TR29	Rehydrated-Weathered	Flat Fragment	Unknown	Unknown	3	3	0%
AK-F01a	Fresh	Cranium: maxilla, zygomatic	Subadult	Ovine	42	--	--
AK-F01b	Fresh	Cranium: maxilla, zygomatic	Subadult	Ovine	47	--	--
AK-F01c	Fresh	Cranium: parietals, occipital, temporals	Subadult	Ovine	215	--	--
AK-F02	Fresh	Mandible	Subadult	Ovine	42	--	--
AK-F03	Fresh	Mandible	Subadult	Ovine	49	--	--
AK-F04	Fresh	Mandible	Subadult	Ovine	51	--	--
AK-F05	Fresh	Mandible	Subadult	Ovine	43	--	--
AK-F06	Fresh	Mandible	Subadult	Ovine	60	--	--
AK-F07	Fresh	Mandible	Subadult	Ovine	55	--	--
AK-F08	Fresh	Femur	Subadult	Ovine	173	--	--
AK-F09	Fresh	Femur	Subadult	Ovine	179	--	--
AK-F10	Fresh	Femur	Subadult	Ovine	170	--	--
AK-F11	Fresh	Femur	Subadult	Ovine	197	--	--
AK-F12	Fresh	Femur	Subadult	Ovine	211	--	--
AK-F13	Fresh	Femur	Subadult	Ovine	202	--	--
AK-F14	Fresh	Femur	Subadult	Ovine	175	--	--
AK-F15	Fresh	Femur	Subadult	Ovine	137	--	--

Mass and Water Content

Specimen	*Group*	*Element*	*Maturity*	*Species*	*Mass$_1$ (g)*	*Mass$_2$ (g)*	*Water Content (%)*
AK-F16	Fresh	Rib	Subadult	Ovine	21	--	--
AK-F17	Fresh	Rib	Subadult	Ovine	16	--	--
AK-F18	Fresh	Rib	Subadult	Ovine	12	--	--
AK-F19	Fresh	Rib	Subadult	Ovine	14	--	--
AK-F20	Fresh	Rib	Subadult	Ovine	10	--	--
AK-F21	Fresh	Rib	Subadult	Ovine	14	--	--
AK-F22	Fresh	Rib	Subadult	Ovine	20	--	--
AK-F23	Fresh	Rib	Subadult	Ovine	10	--	--
AK-F24	Fresh	Rib	Subadult	Ovine	14	--	--
AK-F25	Fresh	Rib	Subadult	Ovine	17	--	--
AK-F26	Fresh	Rib	Subadult	Ovine	15	--	--
AK-F27	Fresh	Rib	Subadult	Ovine	11	--	--
AK-F28	Fresh	Rib	Subadult	Ovine	19	--	--
AK-DC01a	Dry-Control	Cranium: parietals, occipital, temporals	Subadult	Ovine	77	--	--
AK-DC01b	Dry-Control	Cranium: maxilla, zygomatic	Subadult	Ovine	34	--	--
AK-DC01c	Dry-Control	Cranium: maxilla, zygomatic	Subadult	Ovine	32	--	--
AK-DC02	Dry-Control	Mandible	Adult	Ovine	65	--	--
AK-DC03	Dry-Control	Mandible	Adult	Ovine	64	--	--
AK-DC04	Dry-Control	Mandible	Adult	Ovine	37	--	--
AK-DC05	Dry-Control	Humerus	Subadult	Ovine	29	--	--
AK-DC06	Dry-Control	Femur	Subadult	Ovine	29	--	--
AK-DC07	Dry-Control	Tibia	Subadult	Ovine	33	--	--
AK-DC08	Dry-Control	Scapula	Adult	Ovine	29	--	--
AK-DC09	Dry-Control	Scapula	Adult	Ovine	27	--	--
AK-DC10	Dry-Control	Scapula	Adult	Ovine	50	--	--
AK-DC11	Dry-Control	Os Coxa	Adult	Ovine	39	--	--
AK-DC12	Dry-Control	Rib	Adult	Ovine	8	--	--
AK-DC13	Dry-Control	Rib	Adult	Ovine	13	--	--
AK-DC14	Dry-Control	Rib	Adult	Ovine	10	--	--
AK-DC15	Dry-Control	Rib	Adult	Ovine	7	--	--
AK-DC16	Dry-Control	Rib	Adult	Ovine	8	--	--
AK-TD01	Dry-Weathered	Cranium	Adult	Bovine	24	--	--
AK-TD02	Dry-Weathered	Cranium	Adult	Bovine	14	--	--
AK-TD03	Dry-Weathered	Cranium	Adult	Bovine	4	--	--
AK-TD04	Dry-Weathered	Cranium	Adult	Bovine	4	--	--
AK-TD05	Dry-Weathered	Cranium	Adult	Bovine	4	--	--
AK-TD06	Dry-Weathered	Cranium	Adult	Bovine	3	--	--
AK-TD07	Dry-Weathered	Mandible	Adult	Porcine	42	--	--
AK-TD08	Dry-Weathered	Mandible	Adult	Bovine	55	--	--
AK-TD09	Dry-Weathered	Mandible	Adult	Bovine	16	--	--
AK-TD10	Dry-Weathered	Mandible	Adult	Bovine	5	--	--
AK-TD11	Dry-Weathered	Mandible	Adult	Bovine	18	--	--
AK-TD12	Dry-Weathered	Mandible	Adult	Bovine	31	--	--
AK-TD13	Dry-Weathered	Mandible	Adult	Bovine	4	--	--
AK-TD14	Dry-Weathered	Os Coxa	Adult	Bovine	12	--	--
AK-TD15	Dry-Weathered	Os Coxa	Adult	Bovine	7	--	--
AK-TD16	Dry-Weathered	Os Coxa	Adult	Bovine	8	--	--
AK-TD17	Dry-Weathered	Cranium	Unknown	Unknown	5	--	--
AK-TD18	Dry-Weathered	Long Fragment	Unknown	Unknown	2	--	--
AK-TD19	Dry-Weathered	Long Fragment	Unknown	Unknown	4	--	--
AK-TD20	Dry-Weathered	Long Fragment	Unknown	Unknown	8	--	--
AK-TD21	Dry-Weathered	Irregular Fragment	Unknown	Unknown	4	--	--
AK-TD22	Dry-Weathered	Flat Fragment	Unknown	Unknown	4	--	--
AK-TD23	Dry-Weathered	Irregular Fragment	Unknown	Unknown	6	--	--
AK-TD24	Dry-Weathered	Flat Fragment	Unknown	Unknown	6	--	--
AK-TD25	Dry-Weathered	Phalanx (Irregular)	Unknown	Unknown	< 1	--	--
AK-TD26	Dry-Weathered	Flat Fragment	Unknown	Unknown	2	--	--
AK-TD27	Dry-Weathered	Flat Fragment	Unknown	Unknown	3	--	--
AK-TD28	Dry-Weathered	Phalanx (Irregular)	Unknown	Unknown	< 1	--	--
AK-TD29	Dry-Weathered	Irregular Fragment	Unknown	Unknown	4	--	--

Appendix B

Listed below are the raw data collected for radiating fracture lines and fragments from the specimens in each sample group.

Fracture Fragments and Radiating Fracture Lines

Specimen	*Group*	*Element*	*Maturity*	*Species*	*Number of Fragments*	*Fracture Lines*	*Fracture Line Termination*
AK-R01a	Rehydrated	Cranium: parietals, occipital, temporals	Adult	Ovine	3		--
AK-R01b	Rehydrated	Cranium: maxilla, zygomatic	Adult	Ovine	4	X	--
AK-R01c	Rehydrated	Cranium: maxilla, zygomatic	Adult	Ovine	6	X	--
AK-R02	Rehydrated	Mandible	Adult	Ovine	2		
AK-R03	Rehydrated	Mandible	Adult	Ovine	2	X	--
AK-R04	Rehydrated	Mandible	Adult	Ovine	2	X	--
AK-R05	Rehydrated	Mandible	Adult	Ovine	2		
AK-R06	Rehydrated	Mandible	Subadult	Ovine	2	X	--
AK-R07	Rehydrated	Femur	Adult	Ovine	6	X	Epiphysis
AK-R08	Rehydrated	Femur	Subadult	Ovine	3	X	Diaphysis
AK-R09	Rehydrated	Femur	Adult	Ovine	4		
AK-R10	Rehydrated	Femur	Adult	Ovine	3	X	Epiphysis
AK-R11	Rehydrated	Humerus	Subadult	Ovine	6	X	Diaphysis
AK-R12	Rehydrated	Tibia	Adult	Ovine	2	X	Diaphysis
AK-R13	Rehydrated	Humerus	Adult	Ovine	2	X	Epiphysis
AK-R14	Rehydrated	Humerus	Adult	Ovine	3	X	Epiphysis
AK-R15	Rehydrated	Tibia	Adult	Ovine	2	X	Diaphysis
AK-R16	Rehydrated	Tibia	Adult	Ovine	4	X	Epiphysis
AK-R17	Rehydrated	Tibia	Subadult	Ovine	1	X	Epiphysis
AK-R18	Rehydrated	Os Coxa	Adult	Ovine	2	X	--
AK-R19	Rehydrated	Os Coxa	Adult	Ovine	1	X	--
AK-R20	Rehydrated	Os Coxa	Subadult	Ovine	3		
AK-R21	Rehydrated	Os Coxa	Subadult	Ovine	2	X	--
AK-R22	Rehydrated	Scapula	Adult	Ovine	1	X	--
AK-R23	Rehydrated	Scapula	Adult	Ovine	1	X	--
AK-R24	Rehydrated	Scapula	Adult	Ovine	1	X	--
AK-R25	Rehydrated	Scapula	Adult	Ovine	1	X	--
AK-R26	Rehydrated	Scapula	Adult	Ovine	3	X	--
AK-R27	Rehydrated	Scapula	Adult	Ovine	1	X	--
AK-R28	Rehydrated	Scapula	Adult	Ovine	1	X	--
AK-R29	Rehydrated	Scapula	Subadult	Ovine	1	X	--
AK-R30	Rehydrated	Scapula	Adult	Ovine	1	X	--
AK-R31	Rehydrated	Rib	Adult	Ovine	2	X	--
AK-R32	Rehydrated	Rib	Adult	Ovine	1	X	--
AK-R33	Rehydrated	Rib	Subadult	Ovine	2	X	--
AK-R34	Rehydrated	Rib	Adult	Ovine	2	X	--
AK-R35	Rehydrated	Rib	Subadult	Ovine	1	X	--
AK-R36	Rehydrated	Rib	Adult	Ovine	1	X	--
AK-R37	Rehydrated	Rib	Adult	Ovine	1	X	--
AK-R38	Rehydrated	Rib	Adult	Ovine	3	X	--
AK-R39	Rehydrated	Rib	Adult	Ovine	1	X	--
AK-R40	Rehydrated	Rib	Subadult	Ovine	1	X	--
AK-R41	Rehydrated	Rib	Adult	Ovine	1	X	--
AK-R42	Rehydrated	Rib	Adult	Ovine	2		
AK-R43	Rehydrated	Rib	Subadult	Ovine	1	X	--
AK-R44	Rehydrated	Rib	Adult	Ovine	3	X	--
AK-R45	Rehydrated	Rib	Adult	Ovine	2	X	--
AK-R46	Rehydrated	Rib	Adult	Ovine	3	X	--
AK-R47	Rehydrated	Rib	Subadult	Ovine	1	X	--
AK-R48	Rehydrated	Rib	Subadult	Ovine	1		
AK-R49	Rehydrated	Rib	Adult	Ovine	2	X	--
AK-R50	Rehydrated	Rib	Adult	Ovine	1	X	--
AK-R51	Rehydrated	Rib	Subadult	Ovine	1	X	--
AK-R52	Rehydrated	Rib	Subadult	Ovine	1	X	--

Fracture Fragments and Radiating Fracture Lines

Specimen	*Group*	*Element*	*Maturity*	*Species*	*Number of Fragments*	*Fracture Lines*	*Fracture Line Termination*
AK-R53	Rehydrated	Rib	Subadult	Ovine	1	X	--
AK-R54	Rehydrated	Rib	Subadult	Ovine	1	X	--
AK-R55	Rehydrated	Rib	Subadult	Ovine	5	X	--
AK-R56	Rehydrated	Rib	Adult	Ovine	1	X	--
AK-R57	Rehydrated	Rib	Subadult	Ovine	2	X	--
AK-R58	Rehydrated	Rib	Subadult	Ovine	1	X	--
AK-R59	Rehydrated	Rib	Subadult	Ovine	2	X	--
AK-R60	Rehydrated	Rib	Subadult	Ovine	2	X	--
AK-R61	Rehydrated	Rib	Subadult	Ovine	2	X	--
AK-R62	Rehydrated	Rib	Subadult	Ovine	1	X	--
AK-R63	Rehydrated	Rib	Subadult	Ovine	1	X	--
AK-R64	Rehydrated	Rib	Subadult	Ovine	1	X	--
AK-R65	Rehydrated	Rib	Subadult	Ovine	7		
AK-R66	Rehydrated	Rib	Subadult	Ovine	2		
AK-R67	Rehydrated	Rib	Subadult	Ovine	1		
AK-R68	Rehydrated	Rib	Subadult	Ovine	1		
AK-R69	Rehydrated	Rib	Subadult	Ovine	1	X	--
AK-R70	Rehydrated	Rib	Subadult	Ovine	1	X	--
AK-R71	Rehydrated	Rib	Subadult	Ovine	2	X	--
AK-R72	Rehydrated	Rib	Subadult	Ovine	1		
AK-R73	Rehydrated	Rib	Subadult	Ovine	2		
AK-R74	Rehydrated	Rib	Adult	Ovine	1	X	--
AK-TR01	Rehydrated-Weathered	Cranium	Bovine	Adult	7		
AK-TR02	Rehydrated-Weathered	Cranium	Bovine	Adult	4		
AK-TR03	Rehydrated-Weathered	Cranium	Bovine	Adult	9		
AK-TR04	Rehydrated-Weathered	Cranium	Bovine	Adult	5		
AK-TR05	Rehydrated-Weathered	Cranium	Bovine	Adult	5		
AK-TR06	Rehydrated-Weathered	Cranium	Bovine	Adult	5		
AK-TR07	Rehydrated-Weathered	Mandible	Porcine	Adult	2		
AK-TR08	Rehydrated-Weathered	Mandible	Bovine	Adult	5		
AK-TR09	Rehydrated-Weathered	Mandible	Bovine	Adult	3		
AK-TR10	Rehydrated-Weathered	Mandible	Bovine	Adult	2	X	--
AK-TR11	Rehydrated-Weathered	Mandible	Bovine	Adult	6	X	--
AK-TR12	Rehydrated-Weathered	Mandible	Bovine	Adult	2		
AK-TR13	Rehydrated-Weathered	Mandible	Bovine	Adult	1	X	--
AK-TR14	Rehydrated-Weathered	Os Coxa	Bovine	Adult	10	X	--
AK-TR15	Rehydrated-Weathered	Os Coxa	Bovine	Adult	4		
AK-TR16	Rehydrated-Weathered	Os Coxa	Bovine	Adult	8		
AK-TR17	Rehydrated-Weathered	Flat Fragment	Unknown	Unknown	2	X	--
AK-TR18	Rehydrated-Weathered	Os Coxa	Unknown	Unknown	3	X	--
AK-TR19	Rehydrated-Weathered	Long Fragment	Unknown	Unknown	12		
AK-TR20	Rehydrated-Weathered	Long Fragment	Unknown	Unknown	7	X	--
AK-TR21	Rehydrated-Weathered	Tibia	Unknown	Subadult	15		
AK-TR22	Rehydrated-Weathered	Phalanx	Unknown	Unknown	10	X	--
AK-TR23	Rehydrated-Weathered	Long Epiphysis (Irregular)	Unknown	Subadult	8	X	--
AK-TR24	Rehydrated-Weathered	Irregular Fragment	Unknown	Subadult	7	X	--
AK-TR25	Rehydrated-Weathered	Irregular Fragment	Unknown	Unknown	6	X	--
AK-TR26	Rehydrated-Weathered	Long Fragment	Unknown	Unknown	11		
AK-TR27	Rehydrated-Weathered	Caudal Vertebra (Irregular)	Unknown	Unknown	9		
AK-TR28	Rehydrated-Weathered	Long Fragment	Unknown	Unknown	5		
AK-TR29	Rehydrated-Weathered	Flat Fragment	Unknown	Unknown	6		
AK-F01a	Fresh	Cranium: maxilla, zygomatic	Subadult	Ovine	6	X	--
AK-F01b	Fresh	Cranium: maxilla, zygomatic	Subadult	Ovine	4	X	--
AK-F01c	Fresh	Cranium: parietals, occipital, temporals	Subadult	Ovine	4	X	--
AK-F02	Fresh	Mandible	Subadult	Ovine	2		
AK-F03	Fresh	Mandible	Subadult	Ovine	4		
AK-F04	Fresh	Mandible	Subadult	Ovine	4	X	--
AK-F05	Fresh	Mandible	Subadult	Ovine	2		
AK-F06	Fresh	Mandible	Subadult	Ovine	4	X	--
AK-F07	Fresh	Mandible	Subadult	Ovine	3		
AK-F08	Fresh	Femur	Subadult	Ovine	2	X	Epiphysis
AK-F09	Fresh	Femur	Subadult	Ovine	3	X	Epiphysis
AK-F10	Fresh	Femur	Subadult	Ovine	2	X	Diaphysis
AK-F11	Fresh	Femur	Subadult	Ovine	4	X	Epiphysis

Fracture Fragments and Radiating Fracture Lines

Specimen	*Group*	*Element*	*Maturity*	*Species*	*Number of Fragments*	*Fracture Lines*	*Fracture Line Termination*
AK-F12	Fresh	Femur	Subadult	Ovine	3	X	Epiphysis
AK-F13	Fresh	Femur	Subadult	Ovine	13	X	Epiphysis
AK-F14	Fresh	Femur	Subadult	Ovine	3	X	Epiphysis
AK-F15	Fresh	Femur	Subadult	Ovine	2	X	Epiphysis
AK-F16	Fresh	Rib	Subadult	Ovine	2	X	--
AK-F17	Fresh	Rib	Subadult	Ovine	1	X	--
AK-F18	Fresh	Rib	Subadult	Ovine	1		
AK-F19	Fresh	Rib	Subadult	Ovine	1		
AK-F20	Fresh	Rib	Subadult	Ovine	1	X	--
AK-F21	Fresh	Rib	Subadult	Ovine	1	X	--
AK-F22	Fresh	Rib	Subadult	Ovine	1	X	--
AK-F23	Fresh	Rib	Subadult	Ovine	1	X	--
AK-F24	Fresh	Rib	Subadult	Ovine	1	X	--
AK-F25	Fresh	Rib	Subadult	Ovine	1	X	--
AK-F26	Fresh	Rib	Subadult	Ovine	2	X	--
AK-F27	Fresh	Rib	Subadult	Ovine	1	X	--
AK-F28	Fresh	Rib	Subadult	Ovine	1	X	--
AK-DC01a	Dry-Control	Cranium: parietals, occipital, temporals	Subadult	Ovine	13	X	--
AK-DC01b	Dry-Control	Cranium: maxilla, zygomatic	Subadult	Ovine	14		--
AK-DC01c	Dry-Control	Cranium: maxilla, zygomatic	Subadult	Ovine	8	X	--
AK-DC02	Dry-Control	Mandible	Adult	Ovine	2	X	--
AK-DC03	Dry-Control	Mandible	Adult	Ovine	2	X	--
AK-DC04	Dry-Control	Mandible	Adult	Ovine	2	X	--
AK-DC05	Dry-Control	Humerus	Subadult	Ovine	2		
AK-DC06	Dry-Control	Femur	Subadult	Ovine	10		
AK-DC07	Dry-Control	Tibia	Subadult	Ovine	6	X	Diaphysis
AK-DC08	Dry-Control	Scapula	Adult	Ovine	6	X	--
AK-DC09	Dry-Control	Scapula	Adult	Ovine	2	X	--
AK-DC10	Dry-Control	Scapula	Adult	Ovine	4	X	--
AK-DC11	Dry-Control	Os Coxa	Adult	Ovine	2		-
AK-DC12	Dry-Control	Rib	Adult	Ovine	3	X	--
AK-DC13	Dry-Control	Rib	Adult	Ovine	3	X	--
AK-DC14	Dry-Control	Rib	Adult	Ovine	8		
AK-DC15	Dry-Control	Rib	Adult	Ovine	2		
AK-DC16	Dry-Control	Rib	Adult	Ovine	5	X	--
AK-TD01	Dry-Weathered	Cranium	Adult	Bovine	29		
AK-TD02	Dry-Weathered	Cranium	Adult	Bovine	12		
AK-TD03	Dry-Weathered	Cranium	Adult	Bovine	3	X	--
AK-TD04	Dry-Weathered	Cranium	Adult	Bovine	2		
AK-TD05	Dry-Weathered	Cranium	Adult	Bovine	3		
AK-TD06	Dry-Weathered	Cranium	Adult	Bovine	7		
AK-TD07	Dry-Weathered	Mandible	Adult	Porcine	7		
AK-TD08	Dry-Weathered	Mandible	Adult	Bovine	3		
AK-TD09	Dry-Weathered	Mandible	Adult	Bovine	7		
AK-TD10	Dry-Weathered	Mandible	Adult	Bovine	4		
AK-TD11	Dry-Weathered	Mandible	Adult	Bovine	4		
AK-TD12	Dry-Weathered	Mandible	Adult	Bovine	3		
AK-TD13	Dry-Weathered	Mandible	Adult	Bovine	2	X	--
AK-TD14	Dry-Weathered	Os Coxa	Adult	Bovine	10		
AK-TD15	Dry-Weathered	Os Coxa	Adult	Bovine	15		
AK-TD16	Dry-Weathered	Os Coxa	Adult	Bovine	3	X	--
AK-TD17	Dry-Weathered	Cranium	Unknown	Unknown	8		
AK-TD18	Dry-Weathered	Long Fragment	Unknown	Unknown	3		
AK-TD19	Dry-Weathered	Long Fragment	Unknown	Unknown	2		
AK-TD20	Dry-Weathered	Long Fragment	Unknown	Unknown	6		
AK-TD21	Dry-Weathered	Irregular Fragment	Unknown	Unknown	8		
AK-TD22	Dry-Weathered	Flat Fragment	Unknown	Unknown	3		
AK-TD23	Dry-Weathered	Irregular Fragment	Unknown	Unknown	5		
AK-TD24	Dry-Weathered	Flat Fragment	Unknown	Unknown	9	X	--
AK-TD25	Dry-Weathered	Phalanx (Irregular)	Unknown	Unknown	2		
AK-TD26	Dry-Weathered	Flat Fragment	Unknown	Unknown	10		
AK-TD27	Dry-Weathered	Flat Fragment	Unknown	Unknown	9		
AK-TD28	Dry-Weathered	Phalanx (Irregular)	Unknown	Unknown	10		
AK-TD29	Dry-Weathered	Irregular Fragment	Unknown	Unknown	10		

<u>Appendix C</u>

Listed below are the raw data collected for fracture angle, outline, and surface texture from the specimens in each sample group.

Fracture Angle, Outline, and Surface Texture							
Specimen	*Group*	*Element*	*Maturity*	*Species*	*Angle*	*Outline*	*Surface Texture*
AK-R01a	Rehydrated	Cranium: parietals, occipital, temporals	Adult	Ovine	Perpendicular	Intermediate	Rough
AK-R01b	Rehydrated	Cranium: maxilla, zygomatic	Adult	Ovine	Perpendicular	Intermediate	Rough
AK-R01c	Rehydrated	Cranium: maxilla, zygomatic	Adult	Ovine	Perpendicular	Intermediate	Rough
AK-R02	Rehydrated	Mandible	Adult	Ovine	Angled	Intermediate	Rough
AK-R03	Rehydrated	Mandible	Adult	Ovine	Angled	Intermediate	Rough
AK-R04	Rehydrated	Mandible	Adult	Ovine	Angled	Irregular	Mixed
AK-R05	Rehydrated	Mandible	Adult	Ovine	Perpendicular	Intermediate	Rough
AK-R06	Rehydrated	Mandible	Subadult	Ovine	Angled	Intermediate	Rough
AK-R07	Rehydrated	Femur	Adult	Ovine	Angled	Half-butterfly	Mixed
AK-R08	Rehydrated	Femur	Subadult	Ovine	Angled	Half-butterfly	Mixed
AK-R09	Rehydrated	Femur	Adult	Ovine	Angled	Half-butterfly	Mixed
AK-R10	Rehydrated	Femur	Adult	Ovine	Angled	Half-butterfly	Mixed
AK-R11	Rehydrated	Humerus	Subadult	Ovine	Angled	Curved	Mixed
AK-R12	Rehydrated	Tibia	Adult	Ovine	Angled	Curved	Mixed
AK-R13	Rehydrated	Humerus	Adult	Ovine	Perpendicular	Half-butterfly	Rough
AK-R14	Rehydrated	Humerus	Adult	Ovine	Angled	Curved	Smooth
AK-R15	Rehydrated	Tibia	Adult	Ovine	Angled	Half-butterfly	Smooth
AK-R16	Rehydrated	Tibia	Adult	Ovine	Angled	Curved	Smooth
AK-R17	Rehydrated	Tibia	Subadult	Ovine	Angled	Curved	Unobservable
AK-R18	Rehydrated	Os Coxa	Adult	Ovine	Perpendicular	Flat	Rough
AK-R19	Rehydrated	Os Coxa	Adult	Ovine	Perpendicular	Irregular	Rough
AK-R20	Rehydrated	Os Coxa	Subadult	Ovine	Perpendicular	Intermediate	Rough
AK-R21	Rehydrated	Os Coxa	Subadult	Ovine	Perpendicular	Irregular	Smooth
AK-R22	Rehydrated	Scapula	Adult	Ovine	Perpendicular	Flat	Rough
AK-R23	Rehydrated	Scapula	Adult	Ovine	Angled	Irregular	Rough
AK-R24	Rehydrated	Scapula	Adult	Ovine	Angled	Irregular	Rough
AK-R25	Rehydrated	Scapula	Adult	Ovine	Perpendicular	Irregular	Rough
AK-R26	Rehydrated	Scapula	Adult	Ovine	Perpendicular	Irregular	Rough
AK-R27	Rehydrated	Scapula	Adult	Ovine	Perpendicular	Irregular	Rough
AK-R28	Rehydrated	Scapula	Adult	Ovine	Perpendicular	Irregular	Rough
AK-R29	Rehydrated	Scapula	Subadult	Ovine	Perpendicular	Irregular	Rough
AK-R30	Rehydrated	Scapula	Adult	Ovine	Perpendicular	Irregular	Rough
AK-R31	Rehydrated	Rib	Adult	Ovine	Perpendicular	Irregular	Smooth
AK-R32	Rehydrated	Rib	Adult	Ovine	Perpendicular	Irregular	Smooth
AK-R33	Rehydrated	Rib	Subadult	Ovine	Angled	V-Shaped	Smooth
AK-R34	Rehydrated	Rib	Adult	Ovine	Perpendicular	Irregular	Smooth
AK-R35	Rehydrated	Rib	Subadult	Ovine	Perpendicular	V-Shaped	Smooth
AK-R36	Rehydrated	Rib	Adult	Ovine	Perpendicular	Irregular	Smooth
AK-R37	Rehydrated	Rib	Adult	Ovine	Perpendicular	Irregular	Smooth
AK-R38	Rehydrated	Rib	Adult	Ovine	Perpendicular	V-Shaped	Smooth
AK-R39	Rehydrated	Rib	Adult	Ovine	Unobservable	None	Unobservable
AK-R40	Rehydrated	Rib	Subadult	Ovine	Perpendicular	None	Unobservable
AK-R41	Rehydrated	Rib	Adult	Ovine	Perpendicular	Irregular	Unobservable
AK-R42	Rehydrated	Rib	Adult	Ovine	Perpendicular	Flat	Smooth
AK-R43	Rehydrated	Rib	Subadult	Ovine	Perpendicular	Flat	Rough
AK-R44	Rehydrated	Rib	Adult	Ovine	Perpendicular	Irregular	Smooth
AK-R45	Rehydrated	Rib	Adult	Ovine	Perpendicular	Flat	Smooth
AK-R46	Rehydrated	Rib	Adult	Ovine	Perpendicular	Irregular	Smooth
AK-R47	Rehydrated	Rib	Subadult	Ovine	Angled	Irregular	Smooth
AK-R48	Rehydrated	Rib	Subadult	Ovine	Perpendicular	V-Shaped	Unobservable
AK-R49	Rehydrated	Rib	Adult	Ovine	Perpendicular	Irregular	Smooth
AK-R50	Rehydrated	Rib	Adult	Ovine	Angled	Flat	Unobservable
AK-R51	Rehydrated	Rib	Subadult	Ovine	Unobservable	None	Unobservable
AK-R52	Rehydrated	Rib	Subadult	Ovine	Perpendicular	Irregular	Smooth
AK-R53	Rehydrated	Rib	Subadult	Ovine	Angled	Flat	Unobservable

Fracture Angle, Outline, and Surface Texture

Specimen	*Group*	*Element*	*Maturity*	*Species*	*Angle*	*Outline*	*Surface Texture*
AK-R54	Rehydrated	Rib	Subadult	Ovine	Unobservable	None	Unobservable
AK-R55	Rehydrated	Rib	Subadult	Ovine	Perpendicular	Curved	Rough
AK-R56	Rehydrated	Rib	Adult	Ovine	Perpendicular	Flat	Unobservable
AK-R57	Rehydrated	Rib	Subadult	Ovine	Angled	V-Shaped	Smooth
AK-R58	Rehydrated	Rib	Subadult	Ovine	Unobservable	None	Unobservable
AK-R59	Rehydrated	Rib	Subadult	Ovine	Angled	Curved	Smooth
AK-R60	Rehydrated	Rib	Subadult	Ovine	Angled	V-Shaped	Smooth
AK-R61	Rehydrated	Rib	Subadult	Ovine	Perpendicular	Irregular	Smooth
AK-R62	Rehydrated	Rib	Subadult	Ovine	Perpendicular	Flat	Rough
AK-R63	Rehydrated	Rib	Subadult	Ovine	Perpendicular	Flat	Rough
AK-R64	Rehydrated	Rib	Subadult	Ovine	Angled	Irregular	Smooth
AK-R65	Rehydrated	Rib	Subadult	Ovine	Angled	Curved	Rough
AK-R66	Rehydrated	Rib	Subadult	Ovine	Angled	Curved	Smooth
AK-R67	Rehydrated	Rib	Subadult	Ovine	Unobservable	None	Unobservable
AK-R68	Rehydrated	Rib	Subadult	Ovine	Unobservable	None	Unobservable
AK-R69	Rehydrated	Rib	Subadult	Ovine	Unobservable	None	Unobservable
AK-R70	Rehydrated	Rib	Subadult	Ovine	Perpendicular	Irregular	Smooth
AK-R71	Rehydrated	Rib	Subadult	Ovine	Angled	Curved	Smooth
AK-R72	Rehydrated	Rib	Subadult	Ovine	Unobservable	None	Unobservable
AK-R73	Rehydrated	Rib	Subadult	Ovine	Angled	V-Shaped	Smooth
AK-R74	Rehydrated	Rib	Adult	Ovine	Perpendicular	Irregular	Smooth
AK-TR01	Rehydrated-Weathered	Cranium	Bovine	Adult	Perpendicular	Flat	Rough
AK-TR02	Rehydrated-Weathered	Cranium	Bovine	Adult	Perpendicular	Flat	Rough
AK-TR03	Rehydrated-Weathered	Cranium	Bovine	Adult	Perpendicular	Irregular	Rough
AK-TR04	Rehydrated-Weathered	Cranium	Bovine	Adult	Perpendicular	Flat	Rough
AK-TR05	Rehydrated-Weathered	Cranium	Bovine	Adult	Perpendicular	Irregular	Rough
AK-TR06	Rehydrated-Weathered	Cranium	Bovine	Adult	Perpendicular	Flat	Rough
AK-TR07	Rehydrated-Weathered	Mandible	Porcine	Adult	Angled	Flat	Rough
AK-TR08	Rehydrated-Weathered	Mandible	Bovine	Adult	Perpendicular	Irregular	Rough
AK-TR09	Rehydrated-Weathered	Mandible	Bovine	Adult	Perpendicular	Irregular	Rough
AK-TR10	Rehydrated-Weathered	Mandible	Bovine	Adult	Perpendicular	Flat	Rough
AK-TR11	Rehydrated-Weathered	Mandible	Bovine	Adult	Perpendicular	Flat	Rough
AK-TR12	Rehydrated-Weathered	Mandible	Bovine	Adult	Perpendicular	Flat	Rough
AK-TR13	Rehydrated-Weathered	Mandible	Bovine	Adult	Angled	Curved	Mixed
AK-TR14	Rehydrated-Weathered	Os Coxa	Bovine	Adult	Perpendicular	Flat	Rough
AK-TR15	Rehydrated-Weathered	Os Coxa	Bovine	Adult	Perpendicular	Curved	Rough
AK-TR16	Rehydrated-Weathered	Os Coxa	Bovine	Adult	Perpendicular	Irregular	Rough
AK-TR17	Rehydrated-Weathered	Flat Fragment	Unknown	Unknown	Angled	Flat	Smooth
AK-TR18	Rehydrated-Weathered	Os Coxa	Unknown	Unknown	Perpendicular	Flat	Mixed
AK-TR19	Rehydrated-Weathered	Long Fragment	Unknown	Unknown	Angled	Flat	Smooth
AK-TR20	Rehydrated-Weathered	Long Fragment	Unknown	Unknown	Angled	Flat	Smooth
AK-TR21	Rehydrated-Weathered	Tibia	Unknown	Subadult	Unobservable	Pulverised	Rough
AK-TR22	Rehydrated-Weathered	Phalanx	Unknown	Unknown	Angled	Flat	Mixed
AK-TR23	Rehydrated-Weathered	Long Epiphysis (Irregular)	Unknown	Subadult	Perpendicular	Pulverised	Rough
AK-TR24	Rehydrated-Weathered	Irregular Fragment	Unknown	Subadult	Perpendicular	Flat	Rough
AK-TR25	Rehydrated-Weathered	Irregular Fragment	Unknown	Unknown	Perpendicular	Flat	Rough
AK-TR26	Rehydrated-Weathered	Long Fragment	Unknown	Unknown	Perpendicular	Flat	Rough
AK-TR27	Rehydrated-Weathered	Caudal Vertebra (Irregular)	Unknown	Unknown	Perpendicular	Pulverised	Rough
AK-TR28	Rehydrated-Weathered	Long Fragment	Unknown	Unknown	Perpendicular	Irregular	Rough
AK-TR29	Rehydrated-Weathered	Flat Fragment	Unknown	Unknown	Perpendicular	Flat	Rough
AK-F01a	Fresh	Cranium: maxilla, zygomatic	Subadult	Ovine	Perpendicular	Intermediate	Mixed
AK-F01b	Fresh	Cranium: maxilla, zygomatic	Subadult	Ovine	Perpendicular	Intermediate	Mixed
AK-F01c	Fresh	Cranium: parietals, occipital, temporals	Subadult	Ovine	Perpendicular	Intermediate	Mixed
AK-F02	Fresh	Mandible	Subadult	Ovine	Perpendicular	Irregular	Smooth
AK-F03	Fresh	Mandible	Subadult	Ovine	Perpendicular	Irregular	Smooth
AK-F04	Fresh	Mandible	Subadult	Ovine	Angled	Intermediate	Smooth
AK-F05	Fresh	Mandible	Subadult	Ovine	Perpendicular	Intermediate	Mixed
AK-F06	Fresh	Mandible	Subadult	Ovine	Perpendicular	Intermediate	Mixed
AK-F07	Fresh	Mandible	Subadult	Ovine	Perpendicular	Intermediate	Mixed
AK-F08	Fresh	Femur	Subadult	Ovine	Angled	Half-butterfly	Smooth
AK-F09	Fresh	Femur	Subadult	Ovine	Angled	V-shaped	Smooth
AK-F10	Fresh	Femur	Subadult	Ovine	Angled	Irregular	Smooth
AK-F11	Fresh	Femur	Subadult	Ovine	Angled	Half-butterfly	Smooth
AK-F12	Fresh	Femur	Subadult	Ovine	Angled	Half-butterfly	Smooth
AK-F13	Fresh	Femur	Subadult	Ovine	Angled	Half-butterfly	Smooth

Fracture Angle, Outline, and Surface Texture

Specimen	*Group*	*Element*	*Maturity*	*Species*	*Angle*	*Outline*	*Surface Texture*
AK-F14	Fresh	Femur	Subadult	Ovine	Angled	Half-butterfly	Smooth
AK-F15	Fresh	Femur	Subadult	Ovine	Angled	Half-butterfly	Smooth
AK-F16	Fresh	Rib	Subadult	Ovine	Angled	Irregular	Smooth
AK-F17	Fresh	Rib	Subadult	Ovine	Angled	None	Unobservable
AK-F18	Fresh	Rib	Subadult	Ovine	Perpendicular	Flat	Rough
AK-F19	Fresh	Rib	Subadult	Ovine	Unobservable	None	Unobservable
AK-F20	Fresh	Rib	Subadult	Ovine	Angled	Irregular	Unobservable
AK-F21	Fresh	Rib	Subadult	Ovine	Angled	V-shaped	Smooth
AK-F22	Fresh	Rib	Subadult	Ovine	Perpendicular	Flat	Rough
AK-F23	Fresh	Rib	Subadult	Ovine	Angled	Irregular	Mixed
AK-F24	Fresh	Rib	Subadult	Ovine	Unobservable	None	Unobservable
AK-F25	Fresh	Rib	Subadult	Ovine	Angled	Intermediate	Unobservable
AK-F26	Fresh	Rib	Subadult	Ovine	Angled	Irregular	Smooth
AK-F27	Fresh	Rib	Subadult	Ovine	Angled	V-shaped	Unobservable
AK-F28	Fresh	Rib	Subadult	Ovine	Angled	Irregular	Unobservable
AK-DC01a	Dry-Control	Cranium: parietals, occipital, temporals	Subadult	Ovine	Perpendicular	Intermediate	Rough
AK-DC01b	Dry-Control	Cranium: maxilla, zygomatic	Subadult	Ovine	Perpendicular	Intermediate	Rough
AK-DC01c	Dry-Control	Cranium: maxilla, zygomatic	Subadult	Ovine	Perpendicular	Intermediate	Rough
AK-DC02	Dry-Control	Mandible	Adult	Ovine	Perpendicular	Intermediate	Mixed
AK-DC03	Dry-Control	Mandible	Adult	Ovine	Perpendicular	Intermediate	Mixed
AK-DC04	Dry-Control	Mandible	Adult	Ovine	Perpendicular	Intermediate	Mixed
AK-DC05	Dry-Control	Humerus	Subadult	Ovine	Perpendicular	Half-butterfly	Mixed
AK-DC06	Dry-Control	Femur	Subadult	Ovine	Angled	Curved	Mixed
AK-DC07	Dry-Control	Tibia	Subadult	Ovine	Angled	Curved	Mixed
AK-DC08	Dry-Control	Scapula	Adult	Ovine	Perpendicular	Irregular	Rough
AK-DC09	Dry-Control	Scapula	Adult	Ovine	Perpendicular	Irregular	Rough
AK-DC10	Dry-Control	Scapula	Adult	Ovine	Perpendicular	Irregular	Mixed
AK-DC11	Dry-Control	Os Coxa	Adult	Ovine	Perpendicular	Intermediate	Mixed
AK-DC12	Dry-Control	Rib	Adult	Ovine	Perpendicular	Intermediate	Mixed
AK-DC13	Dry-Control	Rib	Adult	Ovine	Angled	Irregular	Mixed
AK-DC14	Dry-Control	Rib	Adult	Ovine	Perpendicular	Irregular	Mixed
AK-DC15	Dry-Control	Rib	Adult	Ovine	Perpendicular	Curved	Mixed
AK-DC16	Dry-Control	Rib	Adult	Ovine	Perpendicular	Irregular	Smooth
AK-TD01	Dry-Weathered	Cranium	Adult	Bovine	Perpendicular	Flat	Rough
AK-TD02	Dry-Weathered	Cranium	Adult	Bovine	Perpendicular	Flat	Rough
AK-TD03	Dry-Weathered	Cranium	Adult	Bovine	Perpendicular	Flat	Rough
AK-TD04	Dry-Weathered	Cranium	Adult	Bovine	Perpendicular	Flat	Rough
AK-TD05	Dry-Weathered	Cranium	Adult	Bovine	Perpendicular	Flat	Rough
AK-TD06	Dry-Weathered	Cranium	Adult	Bovine	Perpendicular	Flat	Rough
AK-TD07	Dry-Weathered	Mandible	Adult	Porcine	Perpendicular	Curved	Rough
AK-TD08	Dry-Weathered	Mandible	Adult	Bovine	Perpendicular	Flat	Mixed
AK-TD09	Dry-Weathered	Mandible	Adult	Bovine	Perpendicular	Flat	Rough
AK-TD10	Dry-Weathered	Mandible	Adult	Bovine	Perpendicular	Flat	Rough
AK-TD11	Dry-Weathered	Mandible	Adult	Bovine	Perpendicular	Flat	Rough
AK-TD12	Dry-Weathered	Mandible	Adult	Bovine	Perpendicular	Flat	Rough
AK-TD13	Dry-Weathered	Mandible	Adult	Bovine	Angled	Flat	Rough
AK-TD14	Dry-Weathered	Os Coxa	Adult	Bovine	Perpendicular	Flat	Rough
AK-TD15	Dry-Weathered	Os Coxa	Adult	Bovine	Perpendicular	Pulverised	Rough
AK-TD16	Dry-Weathered	Os Coxa	Adult	Bovine	Perpendicular	Irregular	Rough
AK-TD17	Dry-Weathered	Cranium	Unknown	Unknown	Perpendicular	Flat	Rough
AK-TD18	Dry-Weathered	Long Fragment	Unknown	Unknown	Angled	Curved	Smooth
AK-TD19	Dry-Weathered	Long Fragment	Unknown	Unknown	Perpendicular	Flat	Rough
AK-TD20	Dry-Weathered	Long Fragment	Unknown	Unknown	Angled	Curved	Smooth
AK-TD21	Dry-Weathered	Irregular Fragment	Unknown	Unknown	Perpendicular	Pulverised	Rough
AK-TD22	Dry-Weathered	Flat Fragment	Unknown	Unknown	Perpendicular	Irregular	Rough
AK-TD23	Dry-Weathered	Irregular Fragment	Unknown	Unknown	Perpendicular	Pulverised	Rough
AK-TD24	Dry-Weathered	Flat Fragment	Unknown	Unknown	Perpendicular	Pulverised	Rough
AK-TD25	Dry-Weathered	Phalanx (Irregular)	Unknown	Unknown	Perpendicular	Pulverised	Mixed
AK-TD26	Dry-Weathered	Flat Fragment	Unknown	Unknown	Perpendicular	Pulverised	Rough
AK-TD27	Dry-Weathered	Flat Fragment	Unknown	Unknown	Perpendicular	Flat	Rough
AK-TD28	Dry-Weathered	Phalanx (Irregular)	Unknown	Unknown	Perpendicular	Pulverised	Mixed
AK-TD29	Dry-Weathered	Irregular Fragment	Unknown	Unknown	Unobservable	Pulverised	Rough

Appendix D

Listed below are the raw data collected for fracture classification from the specimens in each sample group.

Fracture Classification

Specimen	*Group*	*Element*	*Maturity*	*Species*	*Classification*	*Notes*
AK-R01a	Rehydrated	Cranium: parietals, occipital, temporals	Adult	Ovine	Linear	R01a, R01b, and R01c are portions of a single cranium. Masses represent entire cranium prior to separation.
AK-R01b	Rehydrated	Cranium: maxilla, zygomatic	Adult	Ovine	Linear	R01a, R01b, and R01c are portions of a single cranium. Masses represent entire cranium prior to separation.
AK-R01c	Rehydrated	Cranium: maxilla, zygomatic	Adult	Ovine	Linear	R01a, R01b, and R01c are portions of a single cranium. Masses represent entire cranium prior to separation.
AK-R02	Rehydrated	Mandible	Adult	Ovine	Non-Comminuted	
AK-R03	Rehydrated	Mandible	Adult	Ovine	Non-Comminuted	
AK-R04	Rehydrated	Mandible	Adult	Ovine	Non-Comminuted	
AK-R05	Rehydrated	Mandible	Adult	Ovine	Non-Comminuted	
AK-R06	Rehydrated	Mandible	Subadult	Ovine	Incomplete	
AK-R07	Rehydrated	Femur	Adult	Ovine	Spiral	4 attempts to achieve fracture
AK-R08	Rehydrated	Femur	Subadult	Ovine	Transverse	4 attempts to achieve fracture
AK-R09	Rehydrated	Femur	Adult	Ovine	Butterfly	4 attempts to achieve fracture
AK-R10	Rehydrated	Femur	Adult	Ovine	Oblique	
AK-R11	Rehydrated	Humerus	Subadult	Ovine	Oblique	5 attempts to achieve fracture
AK-R12	Rehydrated	Tibia	Adult	Ovine	Oblique	
AK-R13	Rehydrated	Humerus	Adult	Ovine	Incomplete	
AK-R14	Rehydrated	Humerus	Adult	Ovine	Oblique	3 failed attempts Drop height increased to 62 cm
AK-R15	Rehydrated	Tibia	Adult	Ovine	Incomplete	Multiple failed attempts Manually fractured on hammer
AK-R16	Rehydrated	Tibia	Adult	Ovine	Oblique	Multiple failed attempts Manually fractured on hammer
AK-R17	Rehydrated	Tibia	Subadult	Ovine	Spiral	Multiple failed attempts Manually fractured on hammer
AK-R18	Rehydrated	Os Coxa	Adult	Ovine	Incomplete	10 attempts to achieve fracture Mass increased to 3.919 kg
AK-R19	Rehydrated	Os Coxa	Adult	Ovine	Incomplete	4 attempts to achieve fracture
AK-R20	Rehydrated	Os Coxa	Subadult	Ovine	Comminuted	
AK-R21	Rehydrated	Os Coxa	Subadult	Ovine	Incomplete	2 attempts to achieve fracture
AK-R22	Rehydrated	Scapula	Adult	Ovine	Incomplete	
AK-R23	Rehydrated	Scapula	Adult	Ovine	Incomplete	3 attempts to achieve fracture
AK-R24	Rehydrated	Scapula	Adult	Ovine	Incomplete	7 attempts to achieve fracture
AK-R25	Rehydrated	Scapula	Adult	Ovine	Incomplete	
AK-R26	Rehydrated	Scapula	Adult	Ovine	Incomplete	
AK-R27	Rehydrated	Scapula	Adult	Ovine	Incomplete	
AK-R28	Rehydrated	Scapula	Adult	Ovine	Incomplete	
AK-R29	Rehydrated	Scapula	Subadult	Ovine	Incomplete	2 attempts to achieve fracture
AK-R30	Rehydrated	Scapula	Adult	Ovine	Incomplete	3 attempts to achieve fracture
AK-R31	Rehydrated	Rib	Adult	Ovine	Non-Comminuted	
AK-R32	Rehydrated	Rib	Adult	Ovine	Incomplete	
AK-R33	Rehydrated	Rib	Subadult	Ovine	Non-Comminuted	6 attempts to achieve fracture
AK-R34	Rehydrated	Rib	Adult	Ovine	Non-Comminuted	
AK-R35	Rehydrated	Rib	Subadult	Ovine	Incomplete	
AK-R36	Rehydrated	Rib	Adult	Ovine	Incomplete	
AK-R37	Rehydrated	Rib	Adult	Ovine	Incomplete	
AK-R38	Rehydrated	Rib	Adult	Ovine	Comminuted	
AK-R39	Rehydrated	Rib	Adult	Ovine	Incomplete	
AK-R40	Rehydrated	Rib	Subadult	Ovine	Incomplete	

Fracture Classification						
Specimen	*Group*	*Element*	*Maturity*	*Species*	*Classification*	*Notes*
AK-R41	Rehydrated	Rib	Adult	Ovine	Incomplete	
AK-R42	Rehydrated	Rib	Adult	Ovine	Non-Comminuted	
AK-R43	Rehydrated	Rib	Subadult	Ovine	Incomplete	
AK-R44	Rehydrated	Rib	Adult	Ovine	Comminuted	
AK-R45	Rehydrated	Rib	Adult	Ovine	Non-Comminuted	
AK-R46	Rehydrated	Rib	Adult	Ovine	Comminuted	
AK-R47	Rehydrated	Rib	Subadult	Ovine	Incomplete	
AK-R48	Rehydrated	Rib	Subadult	Ovine	Incomplete	
AK-R49	Rehydrated	Rib	Adult	Ovine	Non-Comminuted	
AK-R50	Rehydrated	Rib	Adult	Ovine	Incomplete	
AK-R51	Rehydrated	Rib	Subadult	Ovine	Incomplete	
AK-R52	Rehydrated	Rib	Subadult	Ovine	Incomplete	
AK-R53	Rehydrated	Rib	Subadult	Ovine	Incomplete	
AK-R54	Rehydrated	Rib	Subadult	Ovine	Incomplete	
AK-R55	Rehydrated	Rib	Subadult	Ovine	Incomplete	
AK-R56	Rehydrated	Rib	Adult	Ovine	Incomplete	
AK-R57	Rehydrated	Rib	Subadult	Ovine	Incomplete	
AK-R58	Rehydrated	Rib	Subadult	Ovine	Incomplete	2 attempts to achieve fracture
AK-R59	Rehydrated	Rib	Subadult	Ovine	Non-Comminuted	
AK-R60	Rehydrated	Rib	Subadult	Ovine	Incomplete	
AK-R61	Rehydrated	Rib	Subadult	Ovine	Non-Comminuted	
AK-R62	Rehydrated	Rib	Subadult	Ovine	Incomplete	
AK-R63	Rehydrated	Rib	Subadult	Ovine	Incomplete	
AK-R64	Rehydrated	Rib	Subadult	Ovine	Incomplete	
AK-R65	Rehydrated	Rib	Subadult	Ovine	Comminuted	
AK-R66	Rehydrated	Rib	Subadult	Ovine	Non-Comminuted	
AK-R67	Rehydrated	Rib	Subadult	Ovine	Incomplete	2 attempts to achieve fracture
AK-R68	Rehydrated	Rib	Subadult	Ovine	Incomplete	
AK-R69	Rehydrated	Rib	Subadult	Ovine	Incomplete	
AK-R70	Rehydrated	Rib	Subadult	Ovine	Incomplete	
AK-R71	Rehydrated	Rib	Subadult	Ovine	Non-Comminuted	
AK-R72	Rehydrated	Rib	Subadult	Ovine	Incomplete	4 attempts to achieve fracture
AK-R73	Rehydrated	Rib	Subadult	Ovine	Non-Comminuted	2 attempts to achieve fracture
AK-R74	Rehydrated	Rib	Adult	Ovine	Incomplete	
AK-F01a	Fresh	Cranium: maxilla, zygomatic	Subadult	Ovine	Comminuted	
AK-F01b	Fresh	Cranium: maxilla, zygomatic	Subadult	Ovine	Linear	
AK-F01c	Fresh	Cranium: parietals, occipital, temporals	Subadult	Ovine	Linear	
AK-F02	Fresh	Mandible	Subadult	Ovine	Incomplete	
AK-F03	Fresh	Mandible	Subadult	Ovine	Comminuted	
AK-F04	Fresh	Mandible	Subadult	Ovine	Comminuted	
AK-F05	Fresh	Mandible	Subadult	Ovine	Non-comminuted	
AK-F06	Fresh	Mandible	Subadult	Ovine	Comminuted	
AK-F07	Fresh	Mandible	Subadult	Ovine	Comminuted	
AK-F08	Fresh	Femur	Subadult	Ovine	Oblique	Manually fractured on hammer
AK-F09	Fresh	Femur	Subadult	Ovine	Oblique	Manually fractured on hammer
AK-F10	Fresh	Femur	Subadult	Ovine	Oblique	Manually fractured on hammer
AK-F11	Fresh	Femur	Subadult	Ovine	Oblique	Manually fractured on hammer
AK-F12	Fresh	Femur	Subadult	Ovine	Oblique	Manually fractured on hammer
AK-F13	Fresh	Femur	Subadult	Ovine	Oblique	Manually fractured on hammer
AK-F14	Fresh	Femur	Subadult	Ovine	Oblique	Manually fractured on hammer
AK-F15	Fresh	Femur	Subadult	Ovine	Oblique	Manually fractured on hammer
AK-F16	Fresh	Rib	Subadult	Ovine	Incomplete	Manually bent and broken
AK-F17	Fresh	Rib	Subadult	Ovine	Incomplete	Butchery slice on distal end
AK-F18	Fresh	Rib	Subadult	Ovine	Incomplete	Manually bent and broken
AK-F19	Fresh	Rib	Subadult	Ovine	Incomplete	Manually bent and broken
AK-F20	Fresh	Rib	Subadult	Ovine	Incomplete	Manually bent and broken
AK-F21	Fresh	Rib	Subadult	Ovine	Incomplete	
AK-F22	Fresh	Rib	Subadult	Ovine	Incomplete	
AK-F23	Fresh	Rib	Subadult	Ovine	Incomplete	Manually bent and broken
AK-F24	Fresh	Rib	Subadult	Ovine	Incomplete	
AK-F25	Fresh	Rib	Subadult	Ovine	Incomplete	Manually bent and broken
AK-F26	Fresh	Rib	Subadult	Ovine	Incomplete	
AK-F27	Fresh	Rib	Subadult	Ovine	Incomplete	
AK-F28	Fresh	Rib	Subadult	Ovine	Incomplete	
AK-DC01a	Dry-Control	Cranium: parietals, occipital,	Subadult	Ovine	Comminuted	DC01a, DC01b, and DC 01c are

Fracture Classification

Specimen	*Group*	*Element*	*Maturity*	*Species*	*Classification*	*Notes*
		temporals				portions of a single cranium. 4 attempts to achieve fracture.
AK-DC01b	Dry-Control	Cranium: maxilla, zygomatic	Subadult	Ovine	Comminuted	DC01a, DC01b, and DC 01c are portions of a single cranium.
AK-DC01c	Dry-Control	Cranium: maxilla, zygomatic	Subadult	Ovine	Comminuted	DC01a, DC01b, and DC 01c are portions of a single cranium.
AK-DC02	Dry-Control	Mandible	Adult	Ovine	Non-Comminuted	
AK-DC03	Dry-Control	Mandible	Adult	Ovine	Non-Comminuted	
AK-DC04	Dry-Control	Mandible	Adult	Ovine	Non-Comminuted	
AK-DC05	Dry-Control	Humerus	Subadult	Ovine	Oblique	3 attempts to achieve fracture.
AK-DC06	Dry-Control	Femur	Subadult	Ovine	Spiral	
AK-DC07	Dry-Control	Tibia	Subadult	Ovine	Butterfly	
AK-DC08	Dry-Control	Scapula	Adult	Ovine	Comminuted	
AK-DC09	Dry-Control	Scapula	Adult	Ovine	Non-Comminuted	
AK-DC10	Dry-Control	Scapula	Adult	Ovine	Comminuted	4 attempts to achieve fracture.
AK-DC11	Dry-Control	Os Coxa	Adult	Ovine	Non-Comminuted	
AK-DC12	Dry-Control	Rib	Adult	Ovine	Comminuted	
AK-DC13	Dry-Control	Rib	Adult	Ovine	Comminuted	
AK-DC14	Dry-Control	Rib	Adult	Ovine	Comminuted	
AK-DC15	Dry-Control	Rib	Adult	Ovine	Comminuted	
AK-DC16	Dry-Control	Rib	Adult	Ovine	Comminuted	

Appendix E

Listed below are the raw data collected for tearing, longitudinal splitting, and periosteum peeling from the specimens in each sample group.

Additional Observations							
Specimen	*Group*	*Element*	*Maturity*	*Species*	*Tearing*	*Longitudinal Splitting*	*Periosteum Peeling*
AK-R01a	Rehydrated	Cranium: parietals, occipital, temporals	Adult	Ovine	X	--	
AK-R01b	Rehydrated	Cranium: maxilla, zygomatic	Adult	Ovine	X	--	
AK-R01c	Rehydrated	Cranium: maxilla, zygomatic	Adult	Ovine	X	--	
AK-R02	Rehydrated	Mandible	Adult	Ovine	X	--	
AK-R03	Rehydrated	Mandible	Adult	Ovine		--	
AK-R04	Rehydrated	Mandible	Adult	Ovine	X	--	
AK-R05	Rehydrated	Mandible	Adult	Ovine	X	--	
AK-R06	Rehydrated	Mandible	Subadult	Ovine	X	--	
AK-R07	Rehydrated	Femur	Adult	Ovine		--	
AK-R08	Rehydrated	Femur	Subadult	Ovine		--	
AK-R09	Rehydrated	Femur	Adult	Ovine		--	
AK-R10	Rehydrated	Femur	Adult	Ovine		--	
AK-R11	Rehydrated	Humerus	Subadult	Ovine		--	
AK-R12	Rehydrated	Tibia	Adult	Ovine		--	
AK-R13	Rehydrated	Humerus	Adult	Ovine		--	
AK-R14	Rehydrated	Humerus	Adult	Ovine		--	
AK-R15	Rehydrated	Tibia	Adult	Ovine		--	
AK-R16	Rehydrated	Tibia	Adult	Ovine		--	
AK-R17	Rehydrated	Tibia	Subadult	Ovine		--	
AK-R18	Rehydrated	Os Coxa	Adult	Ovine	X	--	
AK-R19	Rehydrated	Os Coxa	Adult	Ovine	X	--	
AK-R20	Rehydrated	Os Coxa	Subadult	Ovine	X	--	
AK-R21	Rehydrated	Os Coxa	Subadult	Ovine		--	
AK-R22	Rehydrated	Scapula	Adult	Ovine	X	--	
AK-R23	Rehydrated	Scapula	Adult	Ovine	X	--	
AK-R24	Rehydrated	Scapula	Adult	Ovine	X	--	
AK-R25	Rehydrated	Scapula	Adult	Ovine	X	--	
AK-R26	Rehydrated	Scapula	Adult	Ovine	X	--	
AK-R27	Rehydrated	Scapula	Adult	Ovine	X	--	
AK-R28	Rehydrated	Scapula	Adult	Ovine	X	--	
AK-R29	Rehydrated	Scapula	Subadult	Ovine	X	--	
AK-R30	Rehydrated	Scapula	Adult	Ovine	X	--	
AK-R31	Rehydrated	Rib	Adult	Ovine			
AK-R32	Rehydrated	Rib	Adult	Ovine	X	X	
AK-R33	Rehydrated	Rib	Subadult	Ovine			
AK-R34	Rehydrated	Rib	Adult	Ovine			
AK-R35	Rehydrated	Rib	Subadult	Ovine		X	
AK-R36	Rehydrated	Rib	Adult	Ovine			
AK-R37	Rehydrated	Rib	Adult	Ovine	X	X	
AK-R38	Rehydrated	Rib	Adult	Ovine	X		
AK-R39	Rehydrated	Rib	Adult	Ovine	X	X	
AK-R40	Rehydrated	Rib	Subadult	Ovine	X	X	
AK-R41	Rehydrated	Rib	Adult	Ovine			
AK-R42	Rehydrated	Rib	Adult	Ovine			
AK-R43	Rehydrated	Rib	Subadult	Ovine		X	
AK-R44	Rehydrated	Rib	Adult	Ovine			
AK-R45	Rehydrated	Rib	Adult	Ovine	X		
AK-R46	Rehydrated	Rib	Adult	Ovine			
AK-R47	Rehydrated	Rib	Subadult	Ovine			
AK-R48	Rehydrated	Rib	Subadult	Ovine	X	X	
AK-R49	Rehydrated	Rib	Adult	Ovine			
AK-R50	Rehydrated	Rib	Adult	Ovine			
AK-R51	Rehydrated	Rib	Subadult	Ovine	X	X	
AK-R52	Rehydrated	Rib	Subadult	Ovine		X	
AK-R53	Rehydrated	Rib	Subadult	Ovine		X	

Additional Observations							
Specimen	*Group*	*Element*	*Maturity*	*Species*	*Tearing*	*Longitudinal Splitting*	*Periosteum Peeling*
AK-R54	Rehydrated	Rib	Subadult	Ovine	X	X	
AK-R55	Rehydrated	Rib	Subadult	Ovine		X	
AK-R56	Rehydrated	Rib	Adult	Ovine		X	
AK-R57	Rehydrated	Rib	Subadult	Ovine	X		
AK-R58	Rehydrated	Rib	Subadult	Ovine		X	
AK-R59	Rehydrated	Rib	Subadult	Ovine			
AK-R60	Rehydrated	Rib	Subadult	Ovine			
AK-R61	Rehydrated	Rib	Subadult	Ovine			
AK-R62	Rehydrated	Rib	Subadult	Ovine			
AK-R63	Rehydrated	Rib	Subadult	Ovine	X	X	
AK-R64	Rehydrated	Rib	Subadult	Ovine	X	X	
AK-R65	Rehydrated	Rib	Subadult	Ovine	X	X	
AK-R66	Rehydrated	Rib	Subadult	Ovine			
AK-R67	Rehydrated	Rib	Subadult	Ovine		X	
AK-R68	Rehydrated	Rib	Subadult	Ovine		X	
AK-R69	Rehydrated	Rib	Subadult	Ovine		X	
AK-R70	Rehydrated	Rib	Subadult	Ovine			
AK-R71	Rehydrated	Rib	Subadult	Ovine			
AK-R72	Rehydrated	Rib	Subadult	Ovine			
AK-R73	Rehydrated	Rib	Subadult	Ovine		X	
AK-R74	Rehydrated	Rib	Adult	Ovine	X		
AK-F01a	Fresh	Cranium: maxilla, zygomatic	Subadult	Ovine		--	X
AK-F01b	Fresh	Cranium: maxilla, zygomatic	Subadult	Ovine		--	X
AK-F01c	Fresh	Cranium: parietals, occipital, temporals	Subadult	Ovine		--	X
AK-F02	Fresh	Mandible	Subadult	Ovine		--	
AK-F03	Fresh	Mandible	Subadult	Ovine		--	X
AK-F04	Fresh	Mandible	Subadult	Ovine		--	X
AK-F05	Fresh	Mandible	Subadult	Ovine		--	X
AK-F06	Fresh	Mandible	Subadult	Ovine		--	X
AK-F07	Fresh	Mandible	Subadult	Ovine		--	X
AK-F08	Fresh	Femur	Subadult	Ovine		--	
AK-F09	Fresh	Femur	Subadult	Ovine		--	
AK-F10	Fresh	Femur	Subadult	Ovine		--	
AK-F11	Fresh	Femur	Subadult	Ovine		--	
AK-F12	Fresh	Femur	Subadult	Ovine		--	X
AK-F13	Fresh	Femur	Subadult	Ovine		--	X
AK-F14	Fresh	Femur	Subadult	Ovine		--	
AK-F15	Fresh	Femur	Subadult	Ovine		--	X
AK-F16	Fresh	Rib	Subadult	Ovine		X	
AK-F17	Fresh	Rib	Subadult	Ovine		X	
AK-F18	Fresh	Rib	Subadult	Ovine			
AK-F19	Fresh	Rib	Subadult	Ovine		X	
AK-F20	Fresh	Rib	Subadult	Ovine			
AK-F21	Fresh	Rib	Subadult	Ovine			
AK-F22	Fresh	Rib	Subadult	Ovine		X	
AK-F23	Fresh	Rib	Subadult	Ovine			
AK-F24	Fresh	Rib	Subadult	Ovine		X	
AK-F25	Fresh	Rib	Subadult	Ovine		X	
AK-F26	Fresh	Rib	Subadult	Ovine			
AK-F27	Fresh	Rib	Subadult	Ovine		X	
AK-F28	Fresh	Rib	Subadult	Ovine			