

TRAMPLING MODIFICATION:
AN ACTUALISTIC STUDY IN TAPHONOMY

A University Thesis Presented to the Faculty
of
California State University, East Bay

In Partial Fulfillment
of the Requirements for the Degree
Master of Arts in Anthropology

By
Daniel Aaron Cusimano
December 2015

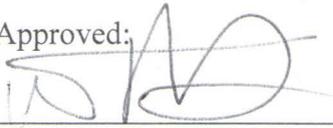
Daniel Cusimano © 2015

TRAMPLING MODIFICATION:
AN ACTUALISTIC STUDY IN TAPHONOMY

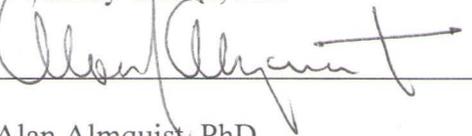
By

Daniel Aaron Cusimano

Approved:



W. Henry Gilbert, PhD



Alan Almquist, PhD

Date:

DEC 03 2015

DEC 03 2015

ACKNOWLEDGEMENTS

This research could not have been completed without the support and guidance from many people. I owe a great deal to Dr. Henry Gilbert who not only helped me to devise the basis of my thesis but welcomed hours of discussion regarding the many variables this research has involved. Also, both Alan Almquist and George Miller helped in this effort by reading through and editing my drafts as well as offering invaluable insight into the fields of faunal analysis and paleoanthropology.

Peter and Nancy Lang of Safari West Wildlife Preserve made this research possible by providing necessary materials and access to their land and animals. Their generosity and enthusiasm regarding this project was beyond what I could have hoped for. Further, this work could not have been accomplished without the ever so much appreciated efforts from Safari West staff. This is particularly true of the Safari West Osteology Lab staff: Jessica Flynn, Mark Pressler, and Marina Lecoeuche. These co-workers and friends struggled through the exhausting task of collecting and analyzing months of data and worked with me every step of the way. I cannot thank them enough.

Finally, I consider myself to be very lucky to have such a supportive girlfriend. Katie has shown ever-enduring patience and support during the many long nights that were required by the project. I couldn't have done it without you.

Table of Contents

List of Figures	vi
List of Tables	vii
Chapter One: Introduction	1
Chapter Two: The Advancement of Hominin Carnivory & Indirect Methods for Analysis	7
Tool-Use in Non-Human Primates	9
Functional Morphology and the Hominin Hand	14
Properties of the Thumb	15
Carpometacarpal Features	17
Interpreting the Fossil Record	18
Bone Density	20
Bone Modification	24
Taphonomic Agents	30
Weathering	31
Butchery	33
Carnivore/Scavenger Gnawing	35
Trampling	36
Chapter Three: Actualistic Experiment in Trampling	49
Materials and Methods	50
Experiment 1: Testing the Efficacy of Game Cameras	51
Experiment 2: Ungulate Trampling	52
Experiment 3: Human Trampling	58
Results	63
Experiment 1: Testing the Efficacy of Game Cameras	63
Experiment 2: Ungulate Trampling	64
Experiment 3: Human Trampling	67
Chapter Four: Ungulate Behavior and Taphonomic Agency	73
Chapter Five: Conclusion	84
References	87

List of Figures

Figure 3.1	Preparation and utilization of impact experiment test plot. A – Digging out and flattening area. B - Ungulate activity over the plot.	51
Figure 3.2	Preparation and utilization of test plots for experiment 2. A – Dumping sediments for Assemblage 4. B – Bones placed for Assemblage 3.	56
Figure 3.3	Two of the four test plots for experiment 3. A- Sediment type 2 w/fragments. B – Sediment type 1 w/fragments.	63
Figure 3.4	Evidence of variable ungulate behavior. A – Buffalo sniffing assemblage. B – Eland fighting over top of assemblage.	66
Figure 3.5	Giraffe osteophagia. A- Masai giraffe with radius in mouth. B – Bone fragment w/ungulate chewing marks.	68
Figure 3.6	Most common forms of damage exhibited in experiment 2. A & B – Fields of parallel striations w/internal striae and shoulder effects. C – Intersecting striae. B – Solitary abrasion.	69
Figure 3.7	Infrequent forms of damage from experiment 2. A – Barb. B, C, & D – Pitting.	70
Figure 3.8	Most common forms of damage exhibited in experiment 3. All images depict short (less than 5 mm) grooves lacking internal striations.	71
Figure 3.9	Infrequent forms of damage from experiment 3. A – Discernible microabrasion. B – Long incision w/internal striae. C – Intersecting grooves with associated microabrasion. D – Conspicuous etchings w/diverse orientations.	72

List of Tables

Table 2.1	Stages of taphonomic weathering as described by Behrensmeier (1986).	32
Table 3.1	Previous experimental research in trampling taphonomy	53
Table 3.2	Assemblage plot description and sediment morphology for experiment 2.	57
Table 3.3	Composition and condition of skeletal sample used in experiment 2.	59
Table 3.4	Modification variables as defined by Dominguz-Rodrigo et al., 2009	60
Table 3.5	Summary of data from experiment 1 (impact)	64
Table 3.6	Activity patterns of animals during experiment 2	65
Table 3.7	Sum of conspicuous damage from experiment 2	65
Table 3.8	Sum of conspicuous damage from experiment 3	70

CHAPTER ONE: INTRODUCTION

Paleoanthropology exists to investigate and illuminate the course of human evolution. While historically this was done almost entirely through the lens of morphological analysis, it has increasingly become an integrative science with connections to research in such fields as archaeology, geology and geochronology, paleoecology (including faunal and botanical specialties), as well as geospatial, isotopic, and genetic analyses. Together these different perspectives help to answer the many questions of when, where, how and under what circumstances our lineage evolved. Difficulties arise, however, when attempting to answer questions concerning the behavior of our human ancestors. Since behavior itself does not fossilize, anthropologists look to the field of taphonomy to discern discrete traces of a wide variety of past activities. While not an exact science, this research has become a necessary component of osteological analysis in zooarchaeology, forensic anthropology, and human origins studies.

Taphonomic investigation has been incorporated into paleontological research since the early 19th century. In short, this area of interest focuses on post-mortem processes that alter organic material. Those who focus in this research investigate all possible agents that have acted on a once living organism (typically vertebrate) from the moment it died to the moment it was recovered in survey or excavation. As a preservative action, taphonomy is best understood as fossilization or, the transition of matter from the biosphere to the lithosphere (Efremov, 1940). While this may be the most widely known taphonomic action, the field also encompasses a range of destructive processes that damage death assemblages. These may include, but are certainly not limited to, the

effects of intensive climactic cycles, chewing and consumption of remains by carnivorous animals, and intensive trampling by other large animals. Thus, as much as taphonomic actions lead to the creation of fossils, these destructive agents are likely more successful in keeping bones and other materials from entering the fossil record. Whether simply modifying the appearance of organic materials or completely destroying them, taphonomic actions can dramatically alter the observable fossil record and, thus, our interpretation of past ecosystems.

In studies of paleoecology, where the goal is to determine species kind, abundance, and interactions, taphonomic factors can be a nuisance by creating a bias towards harder to destroy materials. Because of this destructive biasing, paleontologists often attempt to “strip away” the taphonomic overprint and uncover a clearer depiction of a prehistoric community (Lyman, 1994). In terms of assessing behavior, however, the overprint of these forces holds invaluable information concerning the nature of destructive agents and their activities. This becomes of great anthropological significance in fossil assemblages occurring any time from the Pliocene to the present when human agency must be considered as a potential modifying process.

The most common application of taphonomic analysis in anthropology concerns the reconstruction of human subsistence patterns. Often situated in the narrower field of zooarchaeology, an inspection of faunal elements may lead researchers to answer questions of early human diet, animal procurement strategies, and predator-prey relations (Lyman, 1994). Broadly, these investigations seek to determine if the materials found were initially deposited due to natural processes or as a result of human activity. Bone modifications resulting from human behavior typically occur during the animal butchery

process, or the reduction of carcasses into consumable parts (Lyman, 1987; White, 1992). This process includes the skinning, dismembering, and defleshing of an animal, as well as the extraction of marrow and brain tissue via bone fracture (White, 1992). All of the aforementioned actions may leave diagnostic taphonomic signatures on bone and can be observed as such. The identification of these signatures is one of the most widely used methods employed when discussing ancient human behavior and are typically presented as bone scarring and/or fracturing. Such lines of evidence, however, are difficult to interpret and even more difficult to prove as diagnostic (Binford, 1981).

Perhaps the largest dilemma faced when interpreting taphonomic damage is the fact that different actions can leave marks of similar appearance on bone. Thus, butchery, trampling by large animals, and gnawing by carnivores may all generate fine striations across cortical surfaces (Bunn, 1991). This problem, known as equifinality, reduces the reliability of interpretations that focus on a single series of criteria. To overcome this dilemma most researchers employ a contextual, or “configurational” approach to faunal analysis (Domínguez-Rodrigo et al., 2010). In this way various morphological attributes are considered along with the distribution and orientation of marks as well as the depositional and temporal contexts of fossil assemblages. Here, contextual knowledge lends to probability assessments (i.e. the probable lack of hominin activity at European Pliocene sites), while an analysis of morphology, orientation, and distribution of bone etchings may help to narrow down the list of modifying actors. In paleoanthropological investigation, however, context and mark morphology can still lead to ambiguous interpretations.

Any number of African Plio-Pleistocene fossil sites could provide a convincing case for hominin presence. While researchers are often careful to limit such interpretations to sites containing diagnostic hominin fossils or artifacts, recent years have shown resurgence in a reliance on indirect evidence. This was highlighted by the 2010 claim for humanly modified bones occurring across 3.39 million year old sediments in Ethiopia's Lower Awash Valley. Recovered by the Dikika Research Project (DRP), the fossilized faunal elements, incised with long fine striations, predate previously recognized butchery marks by nearly 800,000 years (McPherron et al., 2010, 2011). While this temporal difference initially draws skepticism, the idea of butchery practices and meat consumption in the Australopith clade is not entirely outlandish (see Ch. 2). The taphonomic evidence presented by the DRP, however, was minimal and unsubstantiated when considered against current knowledge in taphonomy. After having identified the abrasions as "high confidence stone-tool cut marks", critics were quick to question the contextual, anatomical and morphological properties of the found fossils (McPherron et al., 2010; Njau, 2012). Among the critics, Manuel Domínguez-Rodrigo was particularly surprised by the claim that the cortical damage identified did not display the signatures diagnostic of large animal trampling (Domínguez-Rodrigo et al., 2010, 2011). This came from a lack of two commonly recognized trampling features: shallow, randomly distributed microabrasions and intersecting striations of variable depth (Domínguez-Rodrigo et al., 2010). While these traits are often used to identify trampling damage in the fossil record, the retorting authors suggest that their expression requires excellent preservation and is only proven typical of prolonged and intensively trampled bones. The later point calls attention to the variability of trampling activity and mark production.

They further point out that certain morphological aspects of the alleged cut marks do conform to the differential diagnosis.

Confusion in trampling mark identification is perhaps not surprising. Despite more than thirty years of research on this topic, many of the existing publications are in disagreement with each other. This is likely due to the wide variation in experimental and analytical methods applied to the different studies. With differences in assemblage composition and size, underlying sediment types, trampling duration, trampling agents, and methods of analysis, varying results should be expected. While some authors have attempted to reconcile this conflict by employing advanced statistical analyses (Domínguez-Rodrigo et al., 2009), I argue that the hurdles faced by past trampling studies result from methodological errors in the design phase of each experiment.

The current research was designed to add to the literature concerning trampling modification as a taphonomic action capable of mimicking stone tool damage. Instead of focusing on how to differentiate trampling from other forms of bone modification, however, attention is here given to the varying results of past methodologies. To date, no one has performed a trampling experiment where live animals alter relatively fresh bone assemblages. This is, in part, due to the difficulty of reliably performing and monitoring such an experiment as well as the difficulty in obtaining the appropriate resources. To rectify these problems, the current work utilized previously unemployed technology along with the resources available at a large scale African wildlife preserve in Santa Rosa, CA. Thus, a series of experiments were developed to 1) test the reliability of the utilized resources, 2) generate ungulate mediated trampling damage, and 3) compare the results of this experiment with those of the past.

The thesis opens in a way to help the reader first understand the significance of taphonomic interpretation in paleoanthropology. This is done with a review of the different lines of indirect evidence used when inferring behavior in the human fossil record. The focus here is on questions of early hominin carnivory and the implementation of stone tool technologies for resource procurement. The chapter then concludes with a summary of the relatively few attempts at experimental trampling and draws attention to the need for a new methodological approach.

CHAPTER TWO:
THE ADVANCEMENT IN HOMININ CARNIVORY &
INDIRECT METHODS FOR ANALYSIS

The significance of identifying the emergence of stone tools in the archaeological record is twofold. The first and most widely recognized of these impacts highlights the tools themselves. Though not entirely complex at first, this innovation prompted a swift progression in technological achievement that continues today. The other major event associated with emergent stone tools is a shift in the hominin-feeding niche. The co-occurrence of rapid brain expansion and complex lithic technologies is unlikely to be coincidence. The use of stone flakes and cores would have allowed our ancestors to more efficiently process a wider range of resources in a relatively marginal environment. Many speculate that the reliance on this toolkit reflects a subsistence pattern increasingly dependent on animal protein. Further, the regular exploitation of carrion is considered as an impetus for the increased encephalization recognized in the genus *Homo* (Aiello & Wheeler, 1995; Ferraro et al., 2013). Compared to the highly herbivorous resources more readily accessible in a dense forest environment, nutrients provided by vertebrate protein is higher quality and metabolically quicker to process (Aiello & Wheeler, 1995; Jeffares, 2010). Reliance on these resources would have lessened the amount of energy required to break down plant-based foods while simultaneously fueling a metabolically expensive brain. This “expensive-tissue hypothesis” implies that the higher-quality diet was necessary for rapid expansion of the brain and, thus, a catalyst for subsequent cultural innovations (e.g. stone tool industries) (Aiello & Wheeler, 1995).

One of the biggest hurdles in identifying the earliest onset of habitual carnivory has been identifying the earliest tools used for it. Logic dictates that such technological innovations must have first been preceded by an innovation in behavior. While established as a cognitively simple task, the manufacture of even the simplest stone tools (i.e. Mode I) is decidedly more demanding than those assumed in the ape/hominin common ancestor (Stout, 2006). Thus, a reliance on unmodified stones would have likely preceded the emergence of recognizable stone tool industries. Conceptually this is easy to grasp and is evidenced by the commonality of tool using behavior in chimpanzees (*Pan troglodytes*). Unmodified tools, however, are archaeologically invisible. Thus, it is a difficult thing to prove and relies on less direct evidence from the fields of primatology, functional anatomy, and taphonomy. Of these indirect methods, taphonomic analysis provides the only true evidence of butchery behavior. This method is unfortunately limited, however, by the ambiguity of cortical damage. While we attempt to improve our methods in establishing complete taphonomic histories, accepting this evidence begins with considering the potential for early hominins to cognitively and physically make and use stone tools to butcher an animal. If enough evidence exists from the fields of primatology and functional anatomy to advocate tool-using models in Pliocene hominins, we can then scrutinize surficial damage from faunal remains as hominin induced. For this reason it is important to consider what information exists to suggest that pre-*Homo* hominins had acted in this way.

Tool use in non-human primates (cognitive)

The earliest identifiable Oldowan tools come from the site of Gona, Ethiopia and date to about 2.5 Ma (Semaw et al., 1997). Though the site predates the earliest good evidence for the genus *Homo* (though see Villmoare et al., 2015), it is temporally close enough to adhere to a theory set decades before. Louis Leakey was the first to associate stone tools with African hominin assemblages. Though first found with fossils of *Australopithecus boisei*, later discoveries at Olduvai suggested that these implements were the product of a larger brained species. Upon its discovery, this new, relatively gracile Olduvai hominin was declared a member of our own genus. The inclusion was determined in part due to its morphological adaptations (including encephalization) but more expressively because of its association with an emergent tool culture (hence the name *Homo habilis*) (Leakey et al., 1964). Since the established link between the larger brain hominin and stone tools, the common paradigm has worked to exclude smaller brained species from tool using models. Much research since the time of Leakey, however, has worked to establish the morphological and cognitive requirements needed for proficient tool use. The research outlined below elucidates these capacities in modern hominoids and fossil hominins.

There is still little question that tool industries were propagated by members of our genus. Observational and experimental studies with chimpanzees, however, suggest that the earliest origins of tool manufacture may not have been such a great cognitive leap. Chimpanzees, having lesser relative brain size than *Au. africanus* and comparable brain size to *Au. afarensis*, are well-established tool users (Panger et al. 2002). Specifically, the nut-harvesting chimpanzees of West Africa (Ivory Coast, Guinea, and

Liberia) set a good model for early stone tool using capacities in the hominin line. When first documented in 1844, chimpanzees were said to crack nuts in the same manner as humans (Savage & Wyman, 1844). As interest in this activity grew, more detailed investigations depicted the highly intellectual and even cultural nature of chimpanzee tool use. Behaviors which factored into this included preferential selection and transport of materials, mental mapping of resource areas, and transmission of tool using behavior to younger generations.

Christophe and Hedwige Boesch began reporting more thorough accounts of chimpanzees using “natural hammers” in 1981 (Boesch, & Boesch, 1982, 1990). Their work was performed along the N’Zo-Sassandra River in Taï National Park, Ivory Coast, beginning in 1979 and lasted for three years. The chimpanzees in this region processed nuts seasonally, from February to August, and acquired an estimated 3000 calories a day from it (Mercader et al. 2002). The highest value, and most sought after nut in this region grows from the *Panda oleosa* tree. Having too hard a shell to crack with a wooden club, chimps seek out stones of granite and laterite to use as tools. Given the relative scarcity of stones, especially granite, the materials were presumed to have been selected and transported from off-site outcrops as far as 500 m away. Stones were then used excessively for long periods of time (according to use wear) and carried with individuals across different sites (Boesch & Boesch, 1982). During their research the authors noted higher selection for lighter, though adequately hard, hammers when moving to trees farther away. Not being able to see many of these trees at the time of tool selection, it was presumed that they chose stones based on their knowledge of the distance between sites and the costs of carrying a weighted tool.

The importance of *Panda* nuts, and the tools needed to extract them, is further highlighted in these studies by the transmission of nut-cracking strategies to younger troop members. Taught in three stages, young chimpanzees begin to learn to proficiently crack nuts by the time they are three years old. Mothers first leave stones and nuts at an anvil site to stimulate interest in their young. To facilitate the action they allow the then curious infant to take resources from them during harvest. Finally, if the mother does not think the juvenile is properly using the tool, she will actively teach them to do so (Boesch et al., 1994). These behaviors were identified in a single troop on four separate occasions, leading the authors to consider stone tool use as culturally unique to the chimpanzees along the N'Zo-Sassandra River in Taï Park (Boesch et al., 1994). The behaviors exhibited by the Taï Park chimpanzees reflect multiple levels of complex thought beyond that of opportunistic tool use. They portray an understanding of material structure and durability, distribution of resource sites within their environment, and the significance of teaching this behavior to their young.

When such observations are related to discussions of hominin tool use, it is likely safe to assume that the australopiths had the same cognitive capacity for this behavior as modern Great Apes. Problems arise, however, when correlating modern behavioral studies with archaeological populations. To do so appropriately, it becomes necessary to match the material aftermath of chimpanzee tool sites with archaeological sites. Though few in number when compared with hominin tool assemblages, a handful of “chimpanzee stone age” (CSA) sites have been identified in West Africa (Mercader et al., 2002; Mercader et al., 2007). The sites date to roughly 4,300 BP and are isolated from nearby human cultural areas. Among the scatter of nutshells and anvils, researchers at the site of

Panda 1 identified 4,500 grams of fractured stone. Interpreted as the unintentional result of continual percussive actions, the found debitage is said to resemble some earlier Oldowan artifacts. Overall, however, the materials were suggested as too simple to be readily identified as the consequence of tool using without other associated artifacts (Mercader et al., 2002). While too ambiguous to be archaeologically visible on their own, these debitage scatters do provide insight into how flaked tools may have first occurred.

Despite the unintentional production of stone flakes at nut processing sites, however, there have been only few reported cases of apes using flakes as tools, none of which occur in the wild. In contrast, controlled laboratory contexts gave rise to the only occurrence of sophisticated knapping behaviors in non-human primates. This was presented through a series of experiments conducted at the Georgia State University Language Research Center testing the abilities of bonobos to use and manufacture stone tools by way of flint knapping. During this study, Kanzi, an adolescent male bonobo, was trained to create and use a stone flake in the same manner as an experienced human flint-knapper (Nicolas Toth). Over the course of the experiment Kanzi learned to use already prepared flakes to access baited treat boxes. When given only two large stones instead of the already prepared flakes he was forced to attempt the method of flake production taught to him by the authors. Having difficulty mimicking the grips and hand postures exemplified by Toth, Kanzi learned to create large flake scatters by throwing the stones against the hard ground and nearby walls. With time and proper influence, however, Kanzi learned to feebly knap in the manner the authors had hoped and created stone flakes that may have resembled early crude tools (Savage-Rumbaugh & Fields, 2006; Toth et al., 2006). Though this feat was achieved in an experimental setting, Kanzi's

success suggested that, given the right circumstances, chimpanzees are able to use and create flake tools when motivated.

The observations of chimpanzee tool use in the wild and in experimental contexts exemplify the cognitive potential for smaller-brained hominoids to develop tool cultures. While this may contrast the previously held belief that large brains must have preceded tool manufacture, relating this information to hominin fossil species is still limited to conjecture. Furthermore, assuming that australopiths had the cognitive ability to create and use stone tools does not imply that they actually did. If our goal is to determine that pre-*Homo* species were in fact using and potentially manufacturing tools for a specific purpose, it is imperative that it is realized in conjunction with materials found in fossil assemblages. As mentioned before, the earliest stone tools, modified or not, are likely to be archaeologically invisible. Thus, identifying pre-*Homo* habitual tool-use relies on more salient morphological and taphonomic evidence.

If form follows function, morphological manifestations of habitual tool-use should be discernable in the hominin fossil record. This is particularly true if there was a strong selective pressure for such behavior (i.e. increased carnivory). In an investigation into the morphological shifts that might be associated with tool use, many researchers are looking to fossil hominin hands for evidence of advanced manipulative abilities. Once freed from the burdens of locomotion, the human hand could progressively adapt to facilitate fine, but powerful manipulative tasks, including complex tool manufacture (Kivell et al., 2011). For this reason, a number of studies have dedicated considerable time, energy, and resources to determining what morphological adaptations might be manifest in tool using hominins. These analyses have aided in determining which

hominins may have had the physical capability to habitually apply the precision and power necessary to manufacture and use complex stone tools in a similar fashion to modern humans.

Functional anatomy and the hominin hand

One of the most fundamental problems that the bonobo Kanzi faced while learning how to create flakes from cores was not a lack of understanding the process but rather limitations posed by his anatomy. The hand of the chimpanzee, as well as other apes, is designed to facilitate a suspensory and quadrupedal lifestyle. This morphology limited Kanzi's ability to achieve the forceful precision grip necessary for efficient tool manufacture. Though he was eventually able to knap, he did so by resting a stone core on an upturned hand and holding a hammer stone with the radial side of the thumb and proximal index finger of the other. This form of knapping was necessitated by the structure of Kanzi's hand, and demanded many relatively weak strikes to generate a flake (Marzke, 2013). Further, while Kanzi could use a flake to sever a rope during the experiment, the limited mobility of his thumb to his fingers impeded efficient cutting motions. Without reorienting the design of the hand to a form better suited for flake manufacture and use, it seems unlikely that our ancestors would have been able to promote tool industries leading to increased access to high nutrient/easy to process resources.

Kivell et al. propose three stages in hominin hand evolution leading to the current tool using form (2011). Stage one, occurring with the abandonment of a primarily arboreal habitat (~4-3 Ma), is signified by the reduction of the medial digits and

subsequent lengthening of the thumb. The next stage, lasting until about 1.5 Ma represents a transitional period with even further reduction of rays 2-5, a more mobile trapezium-Mc1 articulation, and increased robusticity of the medial metacarpals. The final stage, as might be predicted, reflects the emergence of the modern condition as early as 1.4 Ma (Kivell et al., 2011; Skinner et al., 2015). These stages culminate into the now remarkable efficiency of the modern human hand. In its current condition, our hands have three important tool using/making abilities facilitated by the musculoskeletal arrangement: 1) the ability to stabilize each hand simultaneously during percussive actions (holding both hammerstone and core), 2) the ability to expose the working surfaces of stones by using only the thumb and finger pads, thus reducing the surface area covered by the hand, and 3) the ability to maintain a forceful precision grip at high velocity (Marzke, 2013). These key adaptations, which are detailed below, more precisely involve shorter fingers relative to the thumb, broad apical tufts on the distal phalanges (especially pollical), and larger metacarpal/scaphoid articular surfaces of the trapezium (Kivell et al., 2011; Marzke, 2013).

Properties of the Thumb

The disproportionate length of medial digits to pollex recognized in the human hand helps us to oppose each of our digits. This pad-to-pad precision allows our hands to hold and manipulate objects delicately yet securely between the tip of our thumb and our other fingers (Almécija et al., 2010; Almécija and Alba, 2014; Green and Gordon, 2008). This is achieved by a modification of joint surfaces and muscle attachments found across all manual digits. Incurring the most stressful loads, however, changes to the pollical

metacarpal and phalanges have become the most pronounced. Distally the thumb has broadened through time and developed features that allow it to secure and control objects during manipulation (Almécija et al., 2010; Almécija and Alba, 2014; Green and Gordon, 2008; Marzke, 2013). This Pollical Distal Phalanx (PDP) is marked by a broadening of the apical tuft (distal phalangeal tuberosity) relative to the base, a deep unguis fossa with co-lateral unguis spines, and a pronounced insertion for the *flexor pollicis longus* muscle along its radial surface (Almécija et al., 2010; Marzke, 2013). Apical tufts and unguis fossae coincide with the digital pulp, or finger pad, accentuated in the human thumb. Made up of two components, a fatty proximal portion (overlying the unguis fossa) and a static distal portion (overlying the apical tuft), this pad enables increased friction and stability against an object in grasp (Almécija et al., 2010; Green and Gordon, 2008). In contrast, the non-human hominoid PDP is short and rod shaped with no distal broadening. The gracility of this appendage may be due to the lack of pollical engagement during quadrupedal terrestrial locomotion, only being engaged during suspensory movement (Almécija et al., 2010; Tsegai et al., 2013).

Proximal to the apical tuft is an insertion site for the *flexor pollicis longus* (FPL) muscle of thumb. This muscle, absent in chimpanzees, originates along the anterolateral proximal radius and inserts into the PDP, providing the power and movement necessary for efficient tool use. The FPL acts by flexing the metacarpophalangeal (MP) and the interphalangeal (IP) joints as well as (weakly) flexing the wrist (McKinley and O'Loughlin, 2006). The attachment of this muscle, though found in other catarrhines, is asymmetrically oriented along the radial side of the PDP in humans (marked by a gabled

ridge), enabling a pronating movement during flexion and adding to the precision opposition of the thumb (Almécija et al., 2010; Marzke, 2013).

Finally, like the FPL, the *opponens* muscles of the hand play a large part in developing our grip. One of the unique functional abilities of the human hand is its ability to cup an object with both its radial and ulnar margins. To securely grasp a large object, our hands conform to a variety of shapes and stabilize the thumb and fifth finger against external pressures (Marzke, 2013). This action is largely attributed to the *opponens pollicis & opponens digiti minimi* muscles that produce the torque necessary to firmly oppose the thumb and the little finger. These muscles originate on the flexor retinaculum (carpal tunnel) and have prominent, discernable points of insertion on the radial margin of Mc1 and the medial margin of Mc5 (McKinley and O’Loughlin, 2006). Similarly the proximopalmar metacarpal heads in humans have identifiable bony ‘beaks’ with distal sesamoid bones anchoring the *adductor pollicis oblique* and *flexor pollicis brevis* muscles that increase the moment arm during flexion and abduction of the digits (Kivell et al., 2011). Together, this suite of unique traits in the human PDP (mediolaterally broadened apical tuft, the unguis fossa, the asymmetric insertion of the FPL, and the organization of the *opponens* muscles) support a long and powerful grasping thumb capable of full opposition with its corresponding rays.

Carpometacarpal features

The carpal joints below the thumb are responsible for providing the plane of movement for pollical opposition and for absorbing the stresses incurred by percussive force. The primary movement of the thumb moves along the surface of the trapezium at

the trapeziometacarpal joint. This joint in humans is designed to allow for full opposition of the thumb while protecting it from subluxation. The moderate curvature of both joint surfaces (base of Mc1 and the distal articular surface of the trapezium) is noticeable and attributed to the manipulative abilities of the human hand (Marzke, 2013). Like the metacarpal surface, the scaphoid surface of the trapezium is significantly larger in humans than in apes. This increase in surface area accommodates the increased loads during forceful precision and squeeze gripping (Kivell et al., 2011; Marzke, 2013). Further, the proportionately larger joint surface between the trapezoid and the capitate, along with the general broadening of the bone, help to accommodate the radioulnar stresses during the same motions (Marzke, 2013).

Interpreting Fossil Evidence

All of the aforementioned features are realized in the modern human hand. They are derived to promote a forceful precision grip and to endure the stresses subjected to them during dynamic manipulative action (notably tool use/manufacture). Though they are not the only anatomical changes represented in the modern condition, they have been recognized as some of the most instrumental for our unique manipulative abilities (Marzke, 2013). Further, a number of these traits have been observed in fossil hominins revealing a progressive and mosaic evolutionary history of the human hand. The cases mentioned below do not cover the entire scope of studies in hominin hand evolution but demonstrate how different features manifest through time and may or may not reflect different manipulative abilities.

Isolated hand bones from *Australopithecus afarensis*, representative of the first era in manual evolution proposed by Kivell et al. (2011), suggest that this fossil species had the capability to grasp large objects with considerable force. As opposed to the suspensory form of modern African apes, the observed morphological pattern is considered by some as indicative of the ability to manipulate objects in a pounding or throwing motion. This assertion is supported by the species' relatively short radial digits, proximodistally orientated capitate and basal Mc2, and a proximodistal orientation of the trapezium and basal Mc2. The significance of these traits, however, has been scrutinized, many believing that the species would be incapable of generating the large and repeated internal loads reflective of habitual tool using (Marzke, 2013).

Australopithecus sediba, as described by Berger et al. (2010), shows an even more mosaic combination of morphological traits than *Au. afarensis*. Dating to roughly 1.9 Ma, researchers have uncovered a single remarkably well-preserved specimen (MH2) revealing a nearly complete right hand and a partial left hand. This find has led to the most comprehensive argument for anatomical visibility of habitual tool use in the fossil record. The elements of the MH2 hand reveal a moderately expanded PDP apical tuft, distinct ungual fossa, and a well-developed insertion point for the FPL. The Mc1 of MH2 also presents features representative of moderate manipulative abilities. The prominent beak of the proximo-palmar metacarpal head is flanked by two depressions for large sesamoid bones, helping to increase the moment arm of *adductor pollicis oblique* and *flexor pollicis brevis* muscles. However, the poorly developed muscle attachment sites for the *dorsal interossei* and *opponens pollicis* muscles limit the inferred strength of precision grasping abilities (Kivell et al., 2011). This gracility, along with the primitive

carpometacarpal features may indicate an opportunistic tool user rather than tool manufacturer (Kivell et al., 2011; Marzke, 2011).

Bone Density

While the morphology and orientation of carpal, metacarpal, and phalangeal elements may influence the plausibility of hominin tool using, new investigations into trabecular arrangements and densities in fossil hand bones are providing new insight into activity patterns (Tsegai et al., 2013). Internal bone structure, like external muscle attachment sites, responds to stress incurred from environmental pressures. In 2013, Tsegai et al. published on the trabecular morphology in the third metacarpal head as it relates to three hominoid locomotor behaviors. Utilizing high-resolution microtomography (microCT), the authors were able to assess the entire articular surface of the distal metacarpal. While similar studies have been developed in the past, this is the first attempt at utilizing the relatively small manual elements for analysis. Unlike the joints of the knee and the shoulder, which have been used in the past, the metacarpophalangeal joints directly act on external substrates during quadrupedal and suspensory locomotion and are thus better suited to reflect these activities. The variables assessed during this study included bone volume fraction (BV/TV), trabecular bone stiffness and distribution, and anisotropy (directionality) of trabecular arrangement in the third metacarpal head of all extant hominoid species (including modern humans). In accordance with Wolff's law, the variations of these qualities are all considered as indicators of locomotor and manipulative stress patterns. The resulting data supported

this notion by revealing the distinct differences in manual stress between Asiatic and African apes as well as modern humans.

Habitual suspensory activity in Asian apes requires a distinctive flexed grip over a substrate with body mass (and gravity) concentrated below the hands. During this activity Joint Reaction Forces (JRFs) act mostly on the distal or palmar aspects of the metacarpal head. As was predicted for brachiators, the BV/TV and stiffness was increased in these regions. Given the large range of motion applied during suspensory locomotion the trabecular arrangement showed little directionality. With mass and gravitational forces occurring under the hands and forelimb, JRFs tended to occur almost entirely from contraction of the muscles resulting in low overall BV/TV. Conversely, knuckle-walking places constant downward stress on the dorsal surface of extended metacarpals. Since compressive and joint reaction forces are focused then on the dorsal metacarpal head, this region exhibited considerably increased trabecular density and stiffness. Similarly, the habitual and forceful downward compression placed on the metacarpal heads presented significant anisotropy and an overall greater BV/TV than the suspensory apes (Tsegai et al., 2013)

The modern human hand, while used for a variety of purposes, is notably free from locomotor activities and thus incurs very little joint loading when compared to other hominoids. When used for manipulation the most common hand postures (those engaged in forceful precision or power grips) involve neutral or flexed metacarpophalangeal joints. During these activities JRFs act upon the distal and palmar metacarpal heads in a similar fashion as the Asian apes (though to a much lesser degree). Because of this, modern human hands present generally low trabecular bone density, isotropic orientation

and relatively homogeneous trabecular distribution across the metacarpal head. Though slight, noticeable trabecular concentrations are found in the distal and palmar regions of the head (Tsegai et al., 2013).

The goal of the above study was to determine the variation in trabecular structure relative to peak loading during prolonged hand posture stresses. The knowledge gained from it provided a necessary baseline for interpreting fossil trabecular arrangement but was limited to a narrow set of parameters for testing. For more definitive results a follow-up study reexamined hominoid trabecular structure using a wider range of variables (Skinner et al., 2015). To expand the scope of analysis the authors included a larger set of morphological regions for examination. They additionally included fossil and archaeological specimens in their research in hopes of identifying variation in the human condition. The archaeological specimens used were categorized as recent (1st-3rd century Romans and 4th-6th Century Egyptian Nubians) and late (Qafzeh) *H. sapiens*. These were used because they are established as toolmakers and users. The fossil samples used came from the Neanderthals of Kebara and Amud.

Given the significance of the thumb, as highlighted above, the authors were intent on including the head and base of the first metacarpal in their analysis. The internal morphology of the human Mc1 head and base proved to correspond with *in vivo* grasping experimentation showing palmar concentrations of trabeculae in both regions. While chimpanzees also use their thumbs for manipulation, trabecular data presented a more homogeneous distribution of bone throughout the base. The even arrangement of basal metacarpal trabeculae in this species is thought to reflect the chimpanzee's inability to forcefully oppose the thumb and fingers in a fashion similar to modern humans (Skinner

et al., 2015; Marzke, 2013). Likewise, while grasping an object, the fifth finger in human grip functions to secure it against opposing dynamic forces (Marzke, 2013). This action requires the digit to rotate more than others (via flexion and abduction) during forceful opposition of the thumb (Skinner et al., 2015). The internal force of this action develops trabeculae asymmetrically along the palmar surface of Mc5, reaching proximally along the medial side of the metacarpal head (Marzke, 2013). These features of Mc1 and Mc5 appeared to be unique in humans and were thus determined as diagnostic of habitual manipulative actions (Skinner et al., 2015).

When applying knowledge of these patterns to the archaeological and fossil record distinct similarities unseen in extant apes are noted across many hominin samples. While the earlier known toolmakers (*H. sapiens sapiens* & *H. sapiens neanderthalensis*), presented significantly higher BV/TV when compared to recent *H. sapiens*, the trabecular distributions were nearly identical (i.e. across head and base of Mc1 & medial asymmetry in Mc3 & Mc5 heads). This distributional similarity supports the idea of analogous manipulative activity, while the BV/TV differences are explained as a species-specific disparity in robusticity/gracility (Skinner et al., 2015).

The final part of this study subjected six fossil specimens attributable to *Australopithecus africanus* and other slightly younger South African hominins (SKX 5020, SK 84, StW 418, StW 382, StW 394, and StW 552) to microCT analysis to determine the variation in trabecular density and distribution in the manual elements of Plio-Pleistocene hominins. Only one out of the five fossils analyzed (SKX 5020) differed from known toolmakers in trabecular distribution. Interestingly, this specimen is of an indeterminate species, considered as either early *Homo* or *Au. robustus*. While given little

attention in the article, the density patterns may be useful in determining which of the taxons these elements are affiliated with. All of the *Au. africanus* specimens, however, presented palmar trabecular concentrations in the regions tested (including the base of Mc1), as well as asymmetric trabecular distribution along the palmar and medial surfaces of the metacarpal head. This mosaic set of traits involves a *Pan*-like BV/TV but with a *Homo*-like trabecular distribution.

Despite the supporting evidence for increased manual manipulative behaviors presented by the aforementioned anatomical evidence, it is near impossible to decipher whether or not these changes occurred from stone tool using behaviors or simply from increasing manual manipulative demands after abandoning arboreal life ways. The grasping of objects is not a novel concept in primate behavior. With a reduction in locomotor reliance of the forelimbs, it is not unexpected to observe anatomical properties more reflective of grasping tendencies. Further complications arise from morphological studies when considering the limited availability of fossilized manual elements from the human fossil record. This small sample size is particularly low in the pre-*Homo* assemblages, further reducing the reliability of these studies in their current state.

Bone Modification

Research into the intellect and tool using behaviors of chimpanzees suggests that australopiths likely had the cognitive ability to conceptualize and implement stone tools. Morphological assessments of manual elements from this genus show a mosaic of different traits that may have allowed certain species more dexterous and powerful gripping abilities than that realized in the chimpanzee. Finally, trabecular analysis

suggests that some australopiths were regularly using their hands for tasks more complex than locomotion, as seen in other hominoids. Together, these insights from primatology and functional anatomy present a feasible case for pre-homo tool using faculties. The lines between possibility, plausibility, and proof, however, are distinct, and the “evidence” mentioned above supports little more than possible scenarios for habitual tool-mediated behavior. While proof of this practice is limited to stone tools directly associated with butchered bones, a plausible case may be presented from only the singular presence of characteristically modified bone. For such evidence to be accepted it should adhere to two basic principles: 1) the modified bones are, at very least, temporally associated with stone tools and, 2) the modifications present on bone are discernable from other natural modifying actions. Both of these principles have their limitations and should be considered critically before claims concerning human behavior are made.

Bones have the ability to provide a great deal of information that would otherwise be lost in time. In forensic and archaeological contexts, skeletal analysis has informed on traumatic injury and illness, ancestral affinities, diet, and lifestyle. Bones are also the primary means of taxonomic analysis in paleontological contexts (though genetic sequencing is becoming much more prominent). Further, since the onset of the Pliocene, if found in hominin bearing sediments, animal bones have had to be a part of archaeological analyses. Most famously Raymond Dart asserted that the abundance and condition of faunal remains from South African cave sites (e.g. Makapansgat) proved that australopiths had implemental intelligence, manual dexterity, and a carnivorous diet (Dart, 1949; Hughes, 1954). Perhaps one of the most audacious presumptions in

paleoanthropology, this claim led to decades of deliberation and developed the environment for taphonomic research in anthropological investigation.

Discovery of associated bone and stone tools, spatially and temporally, has a history of inviting interpretations of human behavior. Determining archaeological materials as proof of specific actions, however, is inherently flawed. Archaeologists are limited to seeing products of behavior instead of the processes that create them (Whiten et al., 2009). Further, interpretations are subject to the frame of reference ascribed to by the archaeologist. Thus behavioral interpretations may be subjectively formed and presumptuous (Binford, 1981). History shows that even the direct relation of stone tools and damaged bone can lead to such presumptions. The relationship of these artifacts in ancient assemblages was first given serious credence during 19th century investigations into the antiquity of man (Binford, 1981). Such investigations were undertaken, in part, to establish “man” as an ancient resident of the planet, and relied on associating tools with the remains of extinct animals. To this effect, accounts that identified associated bone and stone tools were considered as direct evidence of a human activity, even without the presence of human remains (Lyell, 1863). This led to a new indirect criterion used to identify paleoanthropological sites: any ancient site that bore artifacts from early humans was considered as a site constructed by man and, in effect, all of the materials found in an archaeological site must have been accumulated and modified by human activity. This anthropocentric frame of reference, as stated by Binford (1981), “resulted in numerous myths regarding man’s ancient past.”

The use of modified bone to identify prehistoric human activity went largely unchallenged in the early years of archaeology. As long as there was supporting evidence

for human presence (i.e. human fossils) there appeared to be no reason to question these assertions. This was especially true because it seemed logical to assume that had always relied on meat and that they were proficient hunters. It wasn't until faunal remains were applied to larger behavioral assertions that this line of evidence came into question.

Dart's killer ape hypothesis rested on the interpretation of faunal remains as part of an australopith osteodontokeratic tool culture. While the South African deposits popularized this paradigm, archaeologists working from Zhoukoudian cave in China first posited the manufacture of a bone tool industry. As a cave deposit, Zhoukoudian yielded wonderfully preserved assemblages. With unmistakable human fossils and crude stone tools, the abundance of splintered bones led archaeologists to believe that the ancient inhabitants were butchering animals and crafting bone tools (Breuil & Boyle, 1939). Further, given that the hominin bones bore the same fracture patterns as the fauna, the authors claimed the Zhoukoudian hominins as cannibals. The fracture patterns discerned by both Weidenrich (1941) and Breuil (1939) were identified as longitudinal in character and resulting from the extraction of marrow from long bones (Binford, 1981). As cannibalism is one of the most poignant taboos in modern society, this claim received attention enough to question the efficacy of taphonomic evidence.

The same year produced one of the earliest experimental studies on the effects of hyena gnawing on long bones. By this time, the involvement of hyenas in bone accumulation and modification had already been considered as a taphonomic factor in cave deposits (Hughes, 1954). Buckland (1823) provided the earliest insight of this process at Kirkdale Cave, Yorkshire. His faunal analysis included descriptions of bite mark morphology, fracture patterns from marrow extraction, and the effects of hyena

spacing over small bones (Buckland 1824). The more dutiful investigation presented by Zapfe (1939), reemphasized bone modification generated by living carnivores. Though Zapfe concluded his depiction of the Zhoukoudian specimens as the likely product of human activity, his work set the stage for later taphonomic debate. This debate, however, had relatively little impact on archaeological discourse. Thus, it wasn't until Dart's similarly provocative interpretations from South Africa did research into bone modification receive significant attention in anthropology (Binford, 1981).

The "Killer Ape" hypothesis proposed by Dart still stands as one of the most well known debates in the history of paleoanthropology. Claiming that early australopiths were savage hunters, Dart based his hypothesis on the accumulation of fractured faunal remains in the same caves as remains of *Australopithecus africanus*. Like Brueil and Boyle in China, the fragmented faunal remains were interpreted as intentionally modified tools representative of a highly intelligent carnivorous species of early human (Dart, 1949; Hughes, 1954). Unlike prior behavioral interpretations, however, the claims were not substantiated by the presence of modified stone tools. This was the first instance of hominin behavior being inferred from only modified faunal remains and, thus, represented a shift in how behavior was interpreted in fossil assemblages (Binford, 1981). Dart diagnosed his osteodontokeratic culture namely by the composition of elements in the Makapansgat assemblage and by the pattern of fracturing evident in much of the sample. With their theory in hand, Dart and his supporters attempted to thwart Buckland's previous assertions that cave assemblages in Africa were comprised by scavenging carnivores (i.e. hyenas). This attempt directly contended Buckland's analysis of Kirkdale Cave nearly 100 years prior.

When presented at the Third Pan-African Congress in 1955, Dart's osteodontokeratic culture and killer ape hypothesis was "brought forcefully" to the attention of Sherwood L. Washburn (Washburn, 1957). Though more interested in extant primates at the time, the hypothesis prompted Washburn to pay close attention to naturally occurring death assemblages while doing research in Wankie Game Reserve, Southern Zimbabwe (formerly Rhodesia). His observation of the faunal refuse left behind by living carnivores matched, in many ways, what was described by Dart as evidence for bone tool industries and head hunting behavior. In a brief publication Washburn relayed these observations noting that the selective eating habits of African carnivores mimicked Dart's hominin bearing cave assemblages and "that the australopithecines were [likely] themselves the game, rather than the hunters" (Washburn, 1957). Like Zapfe before, Washburn took a crucial step in interpreting faunal deposits by looking at modern agents of bone accumulation and modification. Such deliberation was taking further in the 60's and 70's by various authors, few of which were more diligent in their argument than C.K. Brain, who introduced his report of South African cave taphonomy in 1981.

Moving forward with Washburn's observations, the investigation lead by Brain attempted to develop a differential diagnosis explaining the conditions that may have contributed to the state of bones identified as osteodontokeratic tools. Beginning his investigation with the notion that some bones (and parts of bones) are more delicate than others and thus less likely to make it into the fossil record, he planned a series of experiments to examine non-human agents of bone destruction. Through ten years of experimentation in the Namib region of South-West Africa, his investigation revealed bone modifications as they related to subaerial weathering, ungulate trampling, human

butchery, and carnivore/scavenger gnawing (Brain, 1981). While other bone modifying agents have since been identified and examined, much of our current knowledge and interest in taphonomy still involves these primary forces. Brian and Washburn further emphasized the need to question taphonomic evidence as it related to human behavior, noting the ambiguous nature of fossil deposits. Since then archaeologists and paleontologists have been encouraged to support such claims with data gleaned from actualistic experimental designs. The significance of actualism in these studies reflected uniformitarian principles in attempts to recreate conditions most closely akin to what would occur in natural settings. This perspective, as will be highlighted in later chapters, has been a fundamental component of taphonomic research and discourse.

Taphonomic Agents

Taphonomic agency takes a variety of forms. Agency is defined here as an entity's ability to act in a given way within an environment and is specifically concerned with those entities that modify death assemblages. Abiotic modifiers are typically indiscriminate towards the materials they affect. Thus, such actions wear on organic materials as well as inorganic materials. The primary abiotic actions in taphonomy include the effects of weathering, sedimentation, and sedimentary abrasion. These actions alter bones when the remains are left exposed to the elements. Some biotic modifiers act in the same way. The processes of root etching and ungulate trampling each result from the bones resting in the path of the agent. Living taphonomic agents, however, may also affect bone intentionally. The most well-understood bone modifiers are living carnivores and humans. Thus, despite the apparent dichotomy (biotic and abiotic modifications),

taphonomic agency might be better understood as a triad: abiotic, inadvertent biotic, and intentional biotic. While extensive literature exists concerning the many variables that might play into the appearance of carnivore and humanly induced etchings, some of the other taphonomic agents have been less critically considered. The bone modifying effects from ungulate activity, for instance, have been narrowly examined in actualistic terms leading to less reliable accounts and definitions as might be found in other research agendas.

The importance of actualism in taphonomic research is of great concern when demonstrating natural modifying actions. Following uniformitarian principles, actualism refers to the process of mimicking, as close as possible, conditions that would occur under natural circumstances. If these conditions are altered or molded to suit experimental design, the resulting taphonomic conditions are of less value when diagnosing natural agency. The following section highlights some of the taphonomic research that elucidates our current understanding of some of the most well understood modifiers (weathering, carnivore, human) and leads into a detailed account of the experimental work so far achieved in trampling taphonomy.

Weathering

As one of most commonly identified taphonomic actions, weathering has a rapid and relentless affect on bone. Despite its ability to endure longer than most bodily tissues, the chemistry of skeletal components makes it vulnerable to sun exposure, moisture, and daily temperature cycles. C.K. Brain (1967) was one of the first to consider the bone altering effects of intensive solar exposure. Noting a difference in appearance, he stated

that the bone cortex, when left in the heat of Southern Africa, degraded in to a chalky consistency. Structurally this action appeared to weaken bone making weathered elements more susceptible to external damage. As stated above, his conclusions were culminated after a ten-year experiment exposing bones to Namib Desert environment. While explicitly focused on weathering damage effects interpretations of bone tools in fossil assemblages, this work pioneered some of the earliest applications of taphonomic experimentation in anthropology.

Weathering research was then later taken up by Anna K. Behrensmeyer (1978) in attempt to categorize different temporal stages of damage and relate them to specific environmental contexts. Like the work of Brain before, her research stemmed from a broader taphonomic sampling program that took place in Amboseli National Park, Kenya. With a more systematic approach, Behrensmeyer surveyed the experimental assemblage via linear transects through six habitat types: swamp, dense woodland, open woodland, plains, bush, and lakebed (Behrensmeyer, 1978). Through this research a scale of six weathering stages was offered (Table 2.1) that were thought to roughly correlate to a time since death (e.g. bones falling into stages 0, 1, or 2 have been exposed for three years or less). While the research concluded with caution and a call for further inquiry, it strongly suggested that weathering modifications have the potential to impact our understanding of the fossil and archaeological record.

Butchery

From a dietary standpoint, humans, especially ancient humans, and carnivores treat fauna and faunal remains in much the same way. Each class of predator

Table 2.1: Bone weathering stages as described by Behrensmeyer 1978.

Bone Weathering Stage	Description
Stage 0	Bone surface shows no sign of cracking or flaking due to weathering. Usually bone is still greasy, marrow cavities contain tissue, skin and muscle/ligament may cover part or all of the bone surface.
Stage 1	Bone shows cracking, normally parallel to the fiber structure (e.g., longitudinal in long bones). Articular surfaces may show mosaic cracking of covering tissue as well as in the bone itself.
Stage 2	Outermost concentric thin layers of bone show flaking, usually associated with cracks, in that the bone edges along the cracks tend to separate and flake first.
Stage 3	Bone surface is characterized by patches of rough, homogeneously weathered compact bone, resulting in a fibrous texture. In these patches, all the external the external, concentrically layered bone has been removed.
Stage 4	The bone is coarsely fibrous and rough in texture; large and small splinters occur and may be loose enough to fall away from the bone when moved.
Stage 5	Bone is falling apart in situ, with large splinters laying around what remains of the whole, which is fragile and easily broken by moving.

seeks out the bodily regions with the most easily accessible and most nutritious resources. Thus, both prefer large meat bearing limbs and the nutrient rich marrow found inside of bones. The differences in procurement between the two, of course, are methodological. As was the case in Binford's aforementioned analysis, most carnivores employ their teeth as the primary means of resource extraction. Hominins, however, as far as we can tell, relied relatively little on their teeth for meat and marrow procurement and more on hand held implements (i.e. tools) (Binford, 1981). The fact that nearly all taphonomic analyses focus on distinguishing non-human modifications from tool marks highlights the

importance of understanding how this damage manifests on bone. Thus, many experimental studies have been executed with the goal of establishing a set of diagnostic criteria for determining human bone modification (White, 2011). While there can be tremendous variation in the implements used for butchery (stone, wood, bone, shell, etc.) and no way to tell exactly how extinct hominins would use them, most authors utilize a fundamental set of morphological criteria when interpreting butchery marks. These diagnostic features have been determined after years of experimentation in stone tool butchery and are possibly best outlined and illustrated in White (1992, 2011). The following definitions are the most often employed when discussing types of tool-induced markings on bones.

Cutmarks – result from slicing motions, often in skinning and defleshing, in which the blade moves perpendicular to the grain of the tissue being sliced. The resulting marks are typically narrow, fine, and create a deep “V” shape in the bone cortex. These marks are often accompanied by accessory marks, known as “shoulder effects” and “barbs” caused by the irregularities of the tool being used.

Chopmarks – similar to cutmarks, these result from forceful and abrupt interaction between a tool edge and the bone surface. These are functionally similar to carnivore punctures but result in broad, V-shaped cross-sections.

Scrapemarks – these are usually observed as a dense series of superficial, parallel striations that result from dragging a tool across the bone surface. In contrast with the other two categories, scrapemarks are not confined to a single, main groove.

Percussion pits – the identification of percussive action is most often related to marrow extraction in long bones. During such an activity the bone may incur damage

from the tip of the percussive tool (forming a pit), the underlying anvil (forming anvil striae), and/or fracture internally from the impact, resulting in inner conchoidal fracturing of the medullary walls.

Carnivore/Scavenger gnawing

Binford's pivotal work on "middle-range" research and carnivore induced bone modification still stands as a fundamental taphonomic resource today (1981). Similar to Brain's (1981) work on South African cave taphonomy, the impetus for Binford stemmed from the many anthropocentric interpretations of bone modification emerging at the time. To this end he strongly advocated not only for actualism in research design, but also for the research itself to "ask productive questions" and maintain "adequate controls over the experiment" (Binford, 1981). These criteria were emphasized due to the inappropriate nature of many "actualistic" studies at the time. Thus, Binford was careful to utilize skeletal samples from contexts where agency was unambiguously attributed to a single modifying force.

As part of a larger effort to identify seasonal patterns of domestic dog food provisioning in Nunamiut Eskimo villages, Binford developed a framework for identifying carnivore damage in skeletal samples. Referencing a collection of 12,716 sampled from the Eskimo dog yards and supplementing the assemblage with an additional 416 elements from two wolf dens, the study recognized four common morphological features that can be explicitly correlated with carnivore activity. These features were then defined as (a) punctures, (b) pits, (c) scores, and (d) furrows.

- (a) Puncture – Where the bone has collapsed under the pressure of the tooth (typically canine). The size of the puncture is correlated to the strength of the bone relative to the strength of the animal.
- (b) Pitting – Resulting from the same actions as in puncturing but without force enough to collapse the cortical bone.
- (c) Scoring – The result of turning the bone against the teeth or dragging the teeth across the cortex. Appears as scarring on the surface and typically follows the contour of the bone in a linear trajectory.
- (d) Furrowing – Mostly occurring from chewing on the epiphyseal ends, removing most of the cancellous bone. Often appears as undulations or step-like irregularities.

These criteria were given with the caveat that variances would occur with regards to different species. While he observed the potential for variability in carnivore damage, this study rested on the point that distinctive differences exist between humanly modified and carnivore modified samples and that these differences are distinguishable from each other. Species-specific variability, however, has grown in interest since Binford's analysis and now includes a range of large and small mammals (i.e. hyenas, pigs, and rodents) as well as crocodilian and avian modifications. Thus the literature on damage produced by some degree of mastication is vast.

Trampling

Trampling, as a taphonomic activity, differs from the aforementioned actions in that its occurrence is much more disposed to chance. This is true due to 1) the agent's

likely indifference to the assemblage in question and 2) because of the precision needed for agent and object to have direct interaction with each other. Thus, for an assemblage to be trampled it must be lying in the path of the trampling agent or agents. Seldom are the paths of these animals so narrow as to force them over such material scatters, especially in the expansive landscapes of African savannas where much of the consideration in taphonomy is focused. This contrasts the carnivore's desire to feed off of remains and the environment's ubiquitous reach over most depositional contexts.

Trampling also differs from other taphonomic alterations in that it is analyzed for both spatial and physical disturbance. Much attention has been given to the dispersal of surface materials resulting from the movements of large mammals across a landscape. Archaeologists researching site formation processes are careful to consider horizontal and vertical artifact disturbance in sites that may have been exposed to heavy vertebrate traffic. The effects of these dispersal events may distort the perceived association of materials by disarranging articulated skeletons (so that they no longer appear to be from one individual), scattering or mixing bones with other artifacts, or even combining non-contemporaneous cultural layers (Olsen and Shipman, 1988).

The abrasive manifestation of trampled bone, however, is mostly the concern of paleoanthropologists and archaeologists researching resource procurement strategies in early human (or hominin) populations. While tramping itself has little to do with resource allocation, the damage inflicted to bone from this process creates incisive markings that are thought to mimic the marks made by stone tools during the butchery process (Andrews and Cook, 1985; Behrensmeier et al., 1986; Fiorillo, 1987). Thus, when stepped on by large mammals, the pressure placed on a bone may lead to fracturing or, if

the underlying sediment is soft enough, compression of the element into the ground. The later of the two outcomes causes the bone to abrade against the surrounding matrix leaving a variety of etchings across its surface. Depending on the composition and morphology of the surrounding sediments this abrasion will operate in much the same way as a stone tool moving across a bone's surface.

Olsen and Shipman (1988) outline four distinct approaches used by researchers to identify trampling marks and distinguish them from other sources of taphonomic damage. Three of these approaches rely on the examination of bones collected from contexts where trampling is either observed on natural deposits or where the conditions suggest that trampling has occurred over an assemblage. Failures to directly observe the entirety of taphonomic activity in these circumstances, however, make them prone to scrutiny. Direct observation, while difficult to achieve in long-term observational settings, is deemed necessary to ensure that the trampling agents are the only active modifiers over an assemblage (Olsen and Shipman 1988). Because of this many researchers have turned to an alternative method of assessing trampling damage. This fourth approach mentioned (and performed) by the authors involves the development of experimental trampling scenarios.

Three noteworthy trampling experiments were produced throughout the mid to late 1980's. Behrensmeyer, Gordon, and Yanagi published on one of the swiftest and most straightforward of these experiments in 1986. Working with only two sample bones (1 rib and 1 metapodial from domestic horse and cow) they subjected the elements to three minutes of trampling in a coarse substrate with sub-angular sands. The elements were "naturally" cleaned and bore only minor signs of weathering (stage 0-1) before the

experimental process. Like many of the experiments to come, the team decided to use human agents wearing soft-soled shoes to tread across the bones in the damp sand and gravel of a naturally occurring stream. In addition to trampling, the authors intentionally incised the elements with Chalcedony flake tools and a single 4 mm mineral grain adhered to a wooden block. Their intention through this series of experiments was to understand the similarities and differences in mark morphology when each is present within the same sample. Thus, the cut marked bones were assessed before and after they were subjected to the three-minute trampling regime (Behrensmeyer et al., 1986).

The damage produced during trampling was analyzed using a Scanning Electron Microscope (SEM) at magnifications up to 400x. Specifically the authors were looking for differences in cross-sectional, internal, and outer edge (shoulder) morphology. Initial post-trampling observation identified “many obvious scratches” that occurred singly or as sets of parallel marks (Behrensmeyer et al., 1986). Internally, the trampling marks showed both V-shaped and rounded basal cross-sections with internal grooving on some and variability in sharpness of outer edges. The experiment also revealed noteworthy alterations to the pre-existing cut marks that were made with flake tools. Many of the incised striations that were well defined before trampling became “indistinguishable” from the surrounding damage after the experiment (Behrensmeyer et al., 1986). Thus, some of the cut marks became rounded and rough in cross-section with losses of sharp outer margins and internal striae. Contrary to the criteria used for distinguishing cut marks from other damage, these dull, variable morphologies were found adjacent to clearly defined V-shaped incisions produced solely by the trampling activity.

The authors concluded this study by suggesting a multifactorial, or contextual approach to identifying trampling damage. They determined that the use of SEM to assess microscopic features in mark morphology was insufficient as a defining method and should be used in conjunction with an understanding of mark location, orientation, and abundance. Further, they encouraged an understanding of the depositional context for the remains noting that surrounding sediments or burial contexts can be useful in determining the probability of trampling damage versus other taphonomic agents.

Shortly after the work of Behrensmeier et al., Anthony Fiorillo (1987) devised one of the first actualistic trampling experiments utilizing non-human trampling agents. He did so after observing various shallow, sub-parallel cortical abrasions on an assemblage from a mid-Miocene mammal site in southwestern Nebraska. Superficially resembling butchery marks, he suspected that the damage might have been produced during prolonged trampling by Barstovian-age mammals. To test his hypothesis an assemblage of 84 bones was gathered from a nearby ranch. The elements were mostly weathered and belonged to the partial skeletons of 5 cows and a single pig. After an assessment of all existing damage (weathering and carnivore) the remains were placed in a cattle pasture near a salt block that was frequented by a herd of 168 animals. The assemblage was confined to an area measuring approximately 3.5 m and sat atop a hard, dry, sandy soil surface that consisted of fine to coarse sediments (as large as .25-1.00 mm). After an experimental period totaling 4 weeks all of the elements used were collected and inspected for abrasive damage.

During analysis Fiorillo noted that the macroscopically visible shallow, sub-parallel scratches produced during the experiment were readily differentiated from

damage diagnostic of carnivore and rodent tooth abrasions. This perspective, however, did not allow the author to confidently differentiate the trampling damage from butchery damage, prompting him to analyze internal mark morphology with a SEM. The resulting observations were said to be variable in appearance but that many of the marks had internal structure similar to those found from butchered remains (strong V-shaped cross-sections). This was true at magnifications of 160x leading the author to regard trample marks and cutmarks as “indistinguishable” when accounting for variation (Fiorillo, 1987).

A year following Fiorillo’s publication on the similarities of cut marks and trampling marks, Sandra Olsen and Pat Shipman put forward a paper that highlighted their perceived shortcomings of previous research and attempted to overcome them in a finalizing trampling experiment (1988). Here they noted that the experimental approaches accomplished by both Behrensmeyer et al. and Fiorillo were less subject to error than those relying solely on observation but that their use of unnatural conditions and/or old weathered bones had potentially flawed their results (Olsen and Shipman, 1988). Thus, the authors devised an approach that would utilize observational control and fresh bone assemblages, while also including different sediment structures and a lengthier experimental period.

Though the assemblage size is not explicitly stated in their article, a review of the data tables suggests that this project was accomplished with a total of 36 bones that the authors retrieved from a butcher (see Table 1 in Olsen and Shipman, 1988). Representative of domestic sheep and cattle, the bones were situated into four separate assemblages, each containing long bones (n=8), carpals, and tarsals (though mostly

carpals and tarsals). Like Behrensmeyer et al., Olsen and Shipman utilized human instead of ungulate trampling agents and controlled their experiment by isolating each assemblage in plastic trays measuring 43x30x8 cm each. Pea gravel (5-15mm grains), coarse sand (.5-2mm grains), fine sand (.1-.5mm grains), and potting soil were used as the four different sediment types and ranged from sub-angular to well-rounded grain morphologies. To recreate “natural conditions” the authors ensured that their human trampling agents were barefoot and that the experimental period, lasting for a culminated 2 hours per assemblage, was adequately long to mimic a period of months of ungulate trampling.

After each assemblage was thoroughly trampled, the bones from each plot were collected, washed, dried, and inspected with a stereomicroscope before the damaged surfaces were replicated for SEM analysis. Since no surface abrasions developed from the potting soil assemblage, the authors scattered a collection of 23 flint flakes ranging in size from 11-55 mm across the sediment. Equipping people with soft-soled shoes to protect their feet, this assemblage received an addition 1 hour of human trampling. In addition to the isolated sediment trays, Olsen and Shipman developed a supporting experiment to take place in a more naturalistic setting. Undergone at an Upper Paleolithic rock shelter in northwest Greece the authors filled a 1 m², 20 cm deep plot with sterile limestone scree retrieved from the surrounding environment. Separating artifact types by 5 cm sediment layers they added flint flakes, sheep and fish bones to the plot and persuaded ~25 excavators to casually tread across it for a period of a week.

Analysis of the five test assemblages revealed that the long bones of each sample acquired noticeable polish and numerous fine, shallow striations that were widely

distributed and often intersecting. They further revealed, after SEM analysis, that the abrasions caused by trampling were lacking the internal striae known in butchery marks. The smaller carpals and tarsals, on the other hand, acquired very little surface damage, having been buried early in the trampling process. Given that these smaller bones comprised more than 75% of the skeletal sample, the lack of damage accumulated in this experiment is significant. Despite the small sample, however, the authors concluded that, in contrast to the findings of both Behrensmeyer et al. (1986) and Fiorillo (1987), none of the marks generated in their trampling experiments matched cut marks in all details (Olsen and Shipman, 1988). This comment reflects again on the necessity to consider a variety of morphological and contextual criteria when identifying cortical damage. Like Behrensmeyer et al., the authors suggest that sedimentary context be included in analyses but also recommend considering the frequency of modified bone in an assemblage, the number of marks and their distribution found on bone surfaces, the orientation, morphology and depth of abrasions, and the association of these marks with polish (Olsen and Shipman, 1988).

Very little work on the bone modifying effects of trampling was produced after Olsen and Shipman's 1988 publication. While trampling was still a research focus in taphonomy, attention was mostly turned to spatial disturbance in site formation studies and, to a lesser extent, lithic and ceramic damage incurred from trampling agents. It wasn't until 2009 that an effort to reconcile the discrepancies in past morphological research was brought back into the spotlight. In reviewing the work produced by Behrensmeyer et al. (1986), Fiorillo (1984, 1987), and Olsen and Shipman (1988), among a few others, Domínguez-Rodrigo et al. (2009) pointed out the problematic contradictory

criteria established for trampling mark identification. Attention was specifically given to the contrast between Olsen and Shipman's interpretation of internal mark morphology and those of the other experimenters. This difference in opinions mostly focused on whether or not internal morphology was a defining difference between cut marks and trample marks. Papers published from both Behrensmeyer et al. (1986) and Fiorillo (1987) suggested that trampling damage had variable internal morphology that could readily be mistaken for evidence of hominin induced butchery. Further, Behrensmeyer et al. showed that trampling activity could have the effect of distorting the internal morphology of pre-existing butchery marks (1986). Olsen and Shipman, however, challenged this notion stating that a defining trait of cut marks is the inclusion of fine parallel lines within the main striation, and that these were not identified in their experimental series (1988).

Concerning the significance attributed to internal mark morphology, Domínguez-Rodrigo et al. refer to the fragility of microstriations (2009). The susceptibility of this damage to trampling distortion was highlighted early on during the work performed by Behrensmeyer et al. (1986), and was a likely factored into the results of Olsen and Shipman's experiment. Given that the two-hour trampling duration "exceeded that of the previous trampling experiments by a wide margin" there is a high likelihood that any of the internal striae generated were subsequently destroyed (Olsen and Shipman, 1988). Thus, the findings of Olsen and Shipman reaffirm the notion that intensive and prolonged trampling damage is unlikely to preserve internal mark morphology typical of butchery damage. Trampling activity, however, is bound to be variable and can be preserved from short exposure occurrences as well as long. This is the notion promoted by Domínguez-

Rodrigo et al. (2009), who pursued an agenda of identifying low-intensity trampling damage and distinguishing it from butchery damage. This task was performed following a similar set of methods as established by Olsen and Shipman in that the authors utilized isolated sediment samples (n=4) in small square plots and prompted human agents wearing soft soled shoes to trample skeletal assemblages. The primary differences between these experiments are significant, however, and concern the assemblage composition and preparation, as well as trampling elapse time.

The bones used for their experiment were acquired from legal hunting parties and consisted of various ribs and long bones of deer. The remains were butchered with metal tools and then buried for a period of a “few weeks” for degreasing (Domínguez-Rodrigo et al., 2009). After recovering the remains from the burial, each bone was cut into small geometric pieces with an electric hand saw and then boiled in a solution of soap and water to remove any other adhering tissue. Before their use in the trampling exercise, each bone fragment was carefully inspected using hand lenses under strong light for identification of preexisting abrasions. Any such markings were branded using permanent markers so that they would not later be mistaken for experimental marks. In total, the assemblage numbered 220 bone fragments coming from 45 elements. These were then subjected to trampling intervals of 10 seconds and 2 minutes across 4 different sediment types. How the assemblage was divvied up into separate test samples was not stated. Once collected, the fragments were inspected for macroscopically visible marks. Only clearly conspicuous marks were considered, being that they would be most easily mistaken as cut marks and therefore deemed more important for study than the less perceptible damage. The analysis generated a sample of 251 easily observable trampling

abrasions. These marks were then compared to a large sample of lithic cut marks (using simple and retouched tools) produced by students from a Paleolithic Archaeology course at Complutense University, Madrid, Spain. After a thorough analysis of all marks involved in the study, the authors identified a series of morphological and structural features that could be measured for internal and external differences between taphonomic agents (see Table 3.4) (Domínguez-Rodrigo et al., 2009).

The primary achievement of the 2009 article was to develop a list of discriminating variables that might aid the user in differentiating trampling damage from tool marks. The morphological traits that are presented in table 5 were analyzed as three categories (trampling, unretouched tool, and retouched tool) through three different statistical analyses (factorial ANOVA, categorical principal components analysis (CATPCA), and logistic regression analysis). The purpose of this substantial analytical regime, when paired with a greater depth of morphological variables, was to “increase the number of referential analogs on cut mark diversity and trampling/sediment abrasion mark diversity” (Domínguez-Rodrigo et al., 2009). With such an array of tests, the team was able to account for numerous overlapping qualities as well as novel forms of the different damaging effects.

Importantly, this experimental series discerned three trampling qualities that, while common on the intensively trampled remains of Olsen and Shipman’s study, are not typical of the short term trampling assemblage. First, as qualified by Behrensmeier (1986), trampling marks are variable enough to display sharp base and shoulder morphologies as well as the rounded structures otherwise cited (Domínguez-Rodrigo et al., 2009). They then also determined that trampling marks do not necessarily occur in

great abundance or in any noticeable random orientation. This claim also agrees with the conclusions of Behrensmeyer (1986), in that it suggests that a single trample mark may be found and misinterpreted as another form of damage. In addition to these discriminating factors, the experiment supports the notion that cut marks are commonly deeper than trampling marks and that, when applying their list of variables, the internal morphology of a cortical incision can be used to differentiate between taphonomic agents. Thus, trampling marks should present with sinuous groove trajectory and overlapping striae while lacking signs of shoulder effect and flaking on the groove shoulder (Domínguez-Rodrigo et al., 2009). The authors of this study close the paper out with an important caveat stating that it is unclear whether or not the features analyzed during their experiment would apply to all, or even most, trampling contexts. Their approach was specific in that it was designed to develop an understanding of non-intensive trampling. They then suggest that an occurrence of non-intensive trampling might be discerned by first noticing a lack of polish and bone pitting/flaking that were diagnosed after the prolonged experiment of Olsen and Shipman (1988).

The addition of a caveat to the aforementioned research is important for two reasons. First, variation should always be accounted for. This is especially true for taphonomic actions as broad in application as sedimentary abrasion. Various contexts can lead to abrasive damage on bone surfaces and it is unlikely that we will ever be able to account for all of them. The second reason to add such a caveat is that it calls attention to the specifics of experimental design. In this way the article did not suggest that their method could differentiate between trample marks and cut marks. Instead the research suggested that short-term, non-intensive trampling damage could be discerned from cut

marks made with retouched and unretouched flake tools (Domínguez-Rodrigo et al., 2009). To this, however, I would add one more factor to consider in the results of the research. In addition to being non-intensive and short-term trampling, the reader might reflect on the fact that the results are of *human* trampling, not ungulate.

The ungulates of Africa are as abundant as they are variable. They range in size from 2 kg to more than a ton and might travel in herds numbering more than one million individuals. In addition to simply eating, sleeping, and traveling, these animals manage complex social structures, combat (through fight or flight) various predatory advances, and take part in elaborate courting rituals. While possibly unconcerned with the scatters of bones that might lie in their path, any one of these behaviors might occur directly over a death assemblage. To rely on an assumption that this process can be accurately recreated by a handful of human researchers wearing soft-soled shoes is inappropriate. This simple fact was the impetus for the following research. Thus, the second half of this report attempts to provide a clearer understanding of the taphonomic effect of ungulate activity on a bone assemblage.

CHAPTER THREE:
AN ACTUALISTIC EXPERIMENT IN TRAMPLING TAPHONOMY

The experimental effort published by Fiorillo (1987) is one of the only detailed studies in trampling mark distribution and morphology that utilized herds of hoofed mammals (ungulates) as modifying agents. While a number of past trampling experiments have been performed without the use of ungulate agency, these studies are arguably flawed in their design, creating marks that may not have occurred under natural circumstances. The allure of actualism in taphonomic research is that such practices work to recreate an environment that would occur without human intervention, thus mimicking ordinary conditions. Those concerned with actualistic work in trampling, however, have pointed out some pitfalls of these experiments. Such issues concern the materials and methods of analysis used as well as a problem of maintaining direct observation during the course of taphonomic activity, diminishing the ability to account for all disturbance effecting the sampled materials. Hence, Fiorillo used old, weathered bones and was unable to monitor them during the entirety of the experimental process (1987). The use of weathered bones was likely matter of convenience as well as unfamiliarity with the detriments of using such materials. Observational issues in actualistic methods, however, arise from the difficulty of closely monitoring the activity of herd animals over an extended period time. The approach attempted in the current study set out to overcome this obstacle by using motion activated game cameras to monitor taphonomic activity in a large scale African wildlife preserve. Doing so resulted in recordable taphonomic damage solely attributable to the abrasive actions of ungulate movement.

Materials and Methods

The project was conducted at, and with materials from Safari West Wildlife Preserve in Santa Rosa, CA. Safari West is a 400-acre zoological facility in the middle of Sonoma and Napa County's Mayacamas mountain range. With a variety of exotic mammalian and avian species, the facility has an overwhelming emphasis on gregarious African ungulates. While Safari West utilizes some traditional caged enclosures, a majority of the collection is situated in expansive free-roaming mixed species exhibits. This setting promotes herd-mediated behavior that is unseen in many zoological institutions. Herds traverse enclosures that range up to 110-acres in size and do so in association with a variety of other species. This setup allows the animals to navigate large expanses of land while foraging for food (natural growth and provisioned feed), negotiating herd politics (dominance/breeding structures), and establishing/defending territory (inter- and intra-species competition). The unregulated movement and activity of herds creates an ideal environment to test ungulate driven taphonomic activity in an isolated yet semi-wild context.

The entirety of the experimental process was broken up in three phases. The first phase was enacted to develop a method of tracking and understanding the ambulatory impact of an ungulate herd over an isolated plot of land. This helped to establish expectations for the efficacy of camera traps by showing the difference between observed and actual ungulate activity during the experimental period. The second phase was an actualistic trampling experiment utilizing the large integrated herds found at Safari West as taphonomic agents. Finally, the methods employed by Domínguez-Rodrigo et al. (2009) in their "new protocol" for distinguishing trampling damage from butchery marks

were recreated through the Safari West Osteology Lab. The results of this process were compared to the results from the previous experiment to identify any observable differences generated from the two methodological approaches.

Experiment 1

The first phase was developed to promote an understanding of expected ungulate activity over a predetermined measure of land while also allowing for an early assessment of the camera trap technology. This was arranged by delineating a 2x2 meter plot in a frequented expanse in the Safari West cattle pasture. The plot was scraped with rakes and shovels to clear the surface of any vegetation or preexisting hoof prints for each sample period (Fig 3.1). Set in the winter season, rain and overcast skies kept the area soft enough to take impressions of the feet from animals treading over it. The area was thereafter used by the husbandry staff as a feeding ground for the cattle to encourage their presence in the vicinity of the plot. To monitor the daily activity over the test plot, a still photo Buckeye game camera was secured to a nearby tree, roughly 12 meters away.



Figure 3.1: Impact test. 2x2 meter plot tilled and scraped flat (a) and monitored for cattle activity (b).

After a period of 24 hours, the photographic data was retrieved and the condition of the plot was assessed. The cattle at Safari West were able to leave deep well defined prints in the mud after treading over. These prints were then counted to assess the impact, or animal activity over the test area. It was known before the analysis that a precise measure of individual activity could not be assessed from counting hoof prints but along with directionality, the number of prints present in the plot would offer enough information to estimate relative activity patterns. The process was replicated 7 times over the course of three weeks. After each 24-hour period, data from the camera trap was reviewed and compared to the physical condition of the test plot. The camera allowed for observations of the cattle herd passing in and out of the area taking pictures every 15 seconds when animals were present and active. The comparison of the two data sets then allowed for an idea of how much activity is recorded by the camera versus how much activity actually took place.

Experiment 2

The primary trampling experiment was developed with the intention of revealing the taphonomic signature of ungulate induced cortical damage in a naturalistic setting. It was organized after careful consideration of experiments and observations made by Andrews and Cook (1985), Behrensmeier et al., (1986), Fiorillo (1987), Olsen and Shipman (1988), and Domínguez-Rodrigo et al., (2009) (Table 3.1). Each of these authors has contributed to our knowledge of trampling damage, especially as it relates to butchery damage, using a range of different methodologies. To incorporate the effective

measures used by such publications, this experiment used live animals in a fairly controlled yet natural setting, with four different sediment types to account for different environmental contexts and fresh bones (nothing beyond stage 2 weathering) that had not succumbed to human butchery. Further, all pre-existing damage to the sample bones was documented and photographed for later reference, direct observation of the entire experimental process was attempted by use of game cameras, and the experimental period as sufficient enough to ensure the needed activity but short enough to keep from total degradation of materials.

Table 3.1: Summary of previous research in trampling

Author	Type of Study	Duration of Activity	Taphonomic Agent	Setting	Assemblage condition
Andrews & Cook (1985)	Observation	7 Years	Cattle	Natural	Weathered
Behrensmeyer et al. (1986)	Experiment	3 Minutes	Human	Artificial	Fresh
Fiorillo (1987)	Experiment	4 Weeks	Cattle	Natural	Weathered
Olsen & Shipman (1988)	Experiment	2-3 Hours	Human	Artificial	Fresh
Domínguez-Rodrigo et al. (2009)	Experiment	10 Sec-2 Minutes	Human	Artificial	Fresh

The Safari West Osteology Lab (SWOL), established in 2013, provided all of the skeletal materials used for this experiment. The lab is dedicated to the development of a osteological collection representative of their wildlife. This is done for educational (including research) purposes, by utilizing the remains of animals that died naturally at the facility. Thus, recently dead animals are either skeletonized immediately after veterinary led necropsy or allowed a period of natural decomposition (subaerial or subsurface) on Safari West grounds before curation. Most of the subaerial decomposition

takes place at the Northwestern margins of the property in an unaltered environment away from public access. Known as the graveyard, this area is completely exposed to the environment and local wildlife of the Mayacamas region. At elevations ranging between ~500-900 ft. above sea level the hillsides are dominated by oak woodlands and grassy escarpments.

A total of 24 bovid longbones were collected from the Safari West graveyard for use in this experiment (Table 3.3). While specific species were not readily identifiable for most elements at the time of collection, the remains represented both sub-adult and adult African bovids ranging in maximum weight between 150-2000 lbs. When collected, the bones were mostly void of flesh and exhibited slight signs of weathering. Given their location during decomposition there was a chance that local taphonomic processes had acted on these remains before their collection. Expected damage included gnawing from the native wildlife and damage from temperature fluctuations and intensive solar exposure. Some of the animals found in this region that might be responsible for the former modifications include coyote, bobcat, mountain lion, grey fox, raccoon, California ground squirrel, pocket gopher, and turkey vulture. To ensure that this damage was not to be counted in the post-experimental analysis, a thorough inspection of each element preceded their use. This inspection was first accomplished macroscopically and then accompanied by high-resolution digital photography focusing on all diaphyseal surfaces. The photos were then to be used as reference during the later analysis. These elements were then divided into four distinct assemblages to be placed in the animal enclosures.

The assemblages were placed in three mixed exhibit enclosures for periods of six weeks. The location of each assemblage within an enclosure was determined by 1) ease

of access, 2) slope, 3) availability of camera-bearing substrate, and 4) observed animal activity.

- 1) Ease of access was primarily determined our ability to reach this plot during stormy weather (avoidance of roads un-passable in the rain) and animal behavior. Animals that are too aggressive to work around, too often occupied some of the areas originally planned for use.
- 2) Being situated within the Mayacamas mountain range, many of the enclosures have varying slopes that might encourage a greater range of element movement than was desirable. In hopes of not losing elements to fluvial action in the winter, each assemblage was positioned on a relatively flat plot of land.
- 3) Game cameras were a vital part of this project and needed to be secured to monitor each assemblage. For this, each plot needed to be in proximity of a vertical substrate for camera placement.
- 4) To ensure that each assemblage experienced some degree of trampling, the plots needed to be situated in areas where animals were known to frequent. This was accomplished by placing assemblages near resource driven lures (water trough/common feeding area) or in areas that Safari West staff regularly witnessed herd movements.

The three animal enclosures used were referenced by the already established enclosure names provided by Safari West. The first enclosure is the smallest and appropriately named 'the 12-acres' for its size. At the time of this project the enclosure

housed three Masai Giraffe, along with herds of Addax antelope, Grant's gazelle, Roan antelope, Bontebok, Greater Kudu, Bongo, and a flock of Grey Crowned Cranes. Two experimental plots were established in this lot. The second enclosure used is also named for its size. Known as 'the hundred acres', it contained Cape buffalo, Blue Wildebeest, Scimitar-horned Oryx, Ellipsis Waterbuck, Impala, Aoudad, and Ostrich. The final enclosure, not named for size, is called 'Christmas'. The animals in the Christmas enclosure included herds of Zebra, common Eland, Gemsbok, and Ellipsis Waterbuck.



Figure 3.2: Test plots for Experiment 2. Four 2x2 meter plots measuring six inches deep and filled with different sediments.

To account for different pedological contexts, trampling was measured over four 2x2 meter plots. Each plot was dug to a depth of six inches and filled with sediments of different size and angularity (Fig. 3.2). With one exception these sediments were acquired from Ramm Rock and Landscape Supply in Santa Rosa, CA. The fourth sediment type was chosen for its geological context rather than physical properties. Extracted from a naturally occurring deposit at Gilbert Farms in Wheatland, CA, these sediments from the Eastern Sierra Nevada Mountains are said to closely resemble the

morphology of those found throughout Africa's Rift Valley (Woldegabriel, pers. comm.). As might be expected, none of the sediment samples were completely homogenous. Thus, all of them had grains measuring less than 1 mm. There were vast differences, however, maximum grain size and angularity (Table 3.2). The matrix from Gilbert Farms, while predominately fine grained, was mixed with much larger rounded stones.

Table 3.2: Composition and location of experimental trampling plots. The maximum grain size does not reflect the commonality of the grain.

Assemblage/plot #	Enclosure	Sediment size (w/maximum grain size)	Sediment angularity
1	12-acres	Medium ($\leq 8\text{mm}$)	Angular
2	12-acres	Fine ($\leq 5\text{mm}$)	Sub-Angular
3	Christmas	Mixed (up to 5 cm)	Rounded
4	100-acres	Large ($\leq 15\text{mm}$)	Angular

Game cameras were setup to observe each plot and the surrounding area. Each was secured to a nearby tree or fencepost no more than 3 meters from the assemblage it was set to monitor. This was done to 1) ensure that any external force incurred by the assemblage (and thus recorded as taphonomic agency) was in fact from ungulate herds and 2) to observe the degree of activity over each plot. The later would help to determine the likelihood of trampling damage in high traffic settings. After six weeks each assemblage was collected for final analysis. The photos taken by game cameras were collected and analyzed at Safari West by the author and SWOL staff. These photos were assessed to measure how much ungulate traffic occurred in the vicinity of each plot, how

much traffic occurred in the plot, and how many occurrences of direct hoof-to-bone interaction could be accounted for (Table 3.6).

Before any thorough inspection of the skeletal materials was attempted each element was photographed in the same fashion as it was before the experiment. The bones were then cleaned with a soft brush and warm water to thereafter be analyzed using as a model the list of variables outlined in Domínguez-Rodrigo et al., (2009) (Table 3.4). Each element was first examined macroscopically for identification of conspicuous abrasions. These marks were then photographed with a Canon ESO D60 digital camera at high magnification to identify the morphological variables listed in table 5. While careful to not distort the reality of each image, Adobe Photoshop was used to enhance the quality of each shot. This was not an additive process but, working within the recommendations of Gilbert and Richards (2000), adjusted the sharpness and the color curves. These adjustments help to visually clarify the subtle morphological qualities of shallow abrasions.

Experiment 3

Since the primary goal of this project was to determine if experimental trampling marks generated from human agents was sufficient for identification of this activity in paleontological and archaeological collections, it was pertinent to analyze the results of the former with those of the later. Thus, the final experiment was a replication of the most recent and thorough attempt at identifying trampling damage by Domínguez-Rodrigo et al. (2009). This methodology was chosen in part because of its recent addition to the taphonomic literature but also because of its highly artificial approach to the

experimental process. Further, the published account of this experiment gives the most thorough description of trampling mark variability which is used here as reference. The steps here follow this work as close as possible.

Table 3.3: Assemblage composition, distribution, and condition prior to experimentation. *Abrasions present does not include the marks noted under Taphonomy

Specimen #	Element	Assemblage	Relative Age	Abrasions present*	Taphonomy
T1	R Humerus	1	Fused	N	-Weathering stage 1
T2	L Humerus	1	Fused	Y	-Weathering stage 1
T3	L Tibia	1	Unfused	Y	-Weathering stage 1
T4	L Radioulna	1	Fused	N	-Weathering stage 0
T5	L Radioulna	1	Fused	Y	-Weathering stage 2
T6	R Femur	1	Fusing	N	-Weathering stage 1
T7	R Femur	2	Fused	Y	-Weathering stage 1
T8	L Femur	2	Fusing	Y	-Carnivore -Weathering stage 1
T9	R Tibia	2	Fusing	N	-Weathering stage 1
T10	R Radius	2	Fused	N	-Weathering stage 1
T11	L Metacarpal	2	Fused	N	-Weathering stage 1
T12	L Humerus	2	Fusing	N	-Weathering stage 0
T13	L Tibia	3	Fused	Y	-Rodent -Weathering stage 1
T14	L Radius	3	Fused	N	-Weathering stage 1
T15	L Tibia	3	Fusing	Y	-Weathering stage 0
T16	R Femur	3	Fused	N	-Carnivore -Weathering stage 1
T17	R Metacarpal	3	Fused	N	-Weathering stage 0

T18	L Femur	3	Fused	N	-Weathering stage 0
T19	L Radius	4	Unfused	Y	-Weathering stage 1
T20	R Tibia	4	Fused	N	-Weathering stage 0
T21	L Tibia	4	Fusing	N	-Weathering stage 1
T22	R Humerus	4	Fusing	N	-Carnivore -Weathering stage 1
T23	R Femur	4	Fusing	N	-Weathering stage 0
T24	L Humerus	4	Fused	N	-Weathering stage 0

Table 3.4: Analytical variables established by Domínguez-Rodrigo et al. 2009. *Variable number nine is omitted due to its redundancy with variable number eight.

Analytic Variable	Definition
1. Trajectory	Marks can show a straight trajectory (a), a curvy one (b) or a sinuous one (c).
2. Barb	A shallower end of the groove slightly curved to the side in the form of an open hook. Present (a) or absent (b)
3. Orientation	Orientation relative to the bone axis. Can be parallel (a), perpendicular (b) or oblique (c).
4. Shape	Shape of the groove. Can be a narrow V-shape (a) or a wide V-shape (_/) (b).
5. # of grooves	Frequency of marks found on each element or fragment
6. Symmetry of the groove	The section and both sides of the groove can be symmetrical (a) or asymmetrical (b).
7. Shoulder effect	The striae occurring in association with the main groove in a distance not farther than 0.2 mm from the edge of the groove. Present (a) or absent (b).
8. Shoulder flaking*	The presence (over more (a) or less (b) than one-third of the trajectory of one or two

	shoulder of the groove) or absence (c).
10. Overlapping striae	Striae overlapping or running across the main groove with an oblique angle: present (a) or absent (b).
11. Internal microstriations	Observable under 40x magnification. Defined as present (a) or absent (b).
12. Microstriation trajectory	Defined as continuous (a) when it extends along the trajectory all the of the groove or discontinuous (b) when the microstriations are interrupted at more than one instance inside the groove.
13. Shape of microstriation trajectory	Defined as straight (a) or irregular (b).
14. Microstriation location	On the walls of the groove (a), on the bottom (b) or on both (c).
15. Length of main groove	Maximum length in mm.
16. Associated shallow striae (microabrasion)	Away from the main groove and observable with 40x magnification. Defined as present (a) or absent (b).

The experiment started with the acquisition of a recently dead impala (*Aepyceros melampus*) from the Safari West grounds. The author, along with SWOL staff, carefully skeletonized the body with metal tools making sure to avoid contact between tools and bone. Nearly all soft-tissue was removed before the remains were moved to an area for decomposition. Since long bones were the only element type used in experiment 2, axial elements were excluded from this recreation. Thus, only the defleshed impala limb bones were buried for the recommended three-week period (extrapolated from “a few weeks”) (Domínguez-Rodrigo et al., 2009). When the bones were unearthed they were cut into small geometric pieces (<3cm) with an electric handsaw and boiled for a period of 45 minutes. The size of the bone fragments and the boiling time were decided on

subjectively being that these parameters were not specified in the original text. This procedure resulted in an assemblage of 69 bone fragments with clean cortical surfaces. The boiling time was kept at a minimum to reduce risk of damaging the structural integrity of fragments.

This same process was repeated when another cadaver from the same species was acquired. Here the methods differed only in that the remains received an above ground decompositional context. This was done out of convenience. To reduce any potential of weathering, carnivore or scavenger damage, the defleshed limbs were covered with a plastic bucket and weighed down with large stones. This method of aboveground decomposition is the typical practice of the SWOL staff. After cleaning, each fragment was given an identification number and photographed using the same Canon D60 digital camera as was used for experiment 2. This was done to aid in the process of analysis before the experiment and to compare the damage after the experiment. Thus, all novel damage could be identified and compared with the assemblage from the actualistic condition. Weary of any potential difference between the structural integrity of the subterranean and surficial decomposition processes, elements from either batch were labeled with different colored ink (black and red). This would account for any possible difference in methodological approach (though none was expected). With the addition of the second impala the sample size increased to a total of 138 fragments.

For comparative reasons the sediment types used for this experiment were the same as those used from experiment number two. The trampling occurred at 10-second and 2-minute durations by two human agents wearing soft-soled shoes, as was performed

by Domínguez-Rodrigo et al. (2009). The sediments were added to a 2x2' wooden frame made from 2x4" beams. The underlying surface was hard packed clay. Each trampling session was performed over 17 bone fragments that were then collected and bagged separately so that the effects of different sediment types and trampling durations could later be considered (Fig. 3.3). After the experimental period, all bone fragments were rinsed with warm water and analyzed using the same methods that were performed during experiment two.

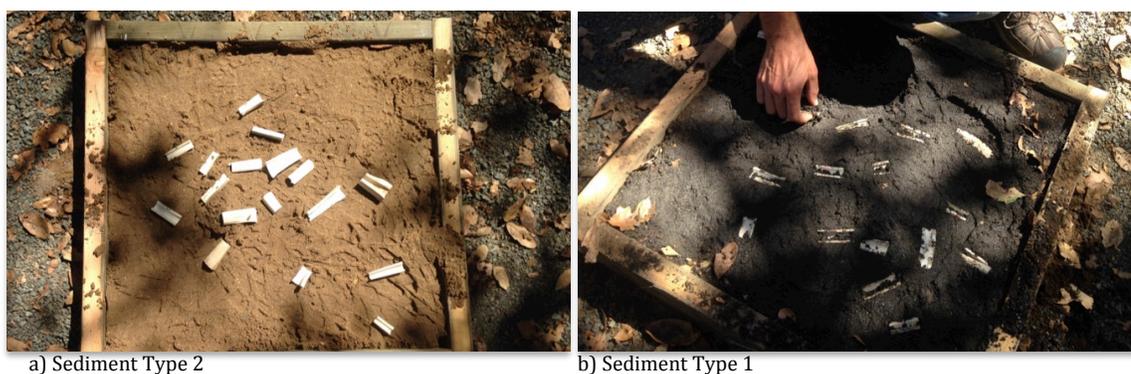


Figure 3.3: Two of four test plots used in experiment 3.

Results

Experiment 1

The impact experiments resulted in a total of 610 photos taken. While a majority of these documented the presence of the Safari West cattle herd (Fig. 3.1b), the cameras also observed the activity of husbandry staff, neighbors with property access, and the researchers working on this project. Of the photos (summarized in Table 3.5), 399 were of the anticipated herd leading to a documented 1910 individual cattle. Though many of these animals were in close proximity to the test area (often just adjacent) only 12

animals were directly observed within the 2x2 meter margins of the plot. Despite this low number, the tallied hoof prints, being documented after each 24-hour test period, resulted in roughly 132 individual impressions. These prints varied in association, size, and trajectory, suggesting that they occurred from more than the minimum number of individuals represented by the sum (total number of prints divided by the number of hooves per animal ($132 \div 4$)). Thus, the calculated hoof prints imply that more than double the photographed animals passed over the test area.

Table 3.5: Summarized data from impact experiments

Date	# of photos	# of photos w/animals	# of animals	# of photos with animals in plot	# of animals in plot	# of hoof prints
12/07/2014	132	130	679	0	0	32
12/23/2014	0	0	0	0	0	0
12/27/2014	84	50	281	0	0	9
12/28/2014	78	36	232	0	0	24
01/02/2015	150	132	532	10	7	40
01/03/2014	112	14	33	0	0	8
01/09/2014	54	37	153	4	5	19
Totals	610	399	1910	14	12	132

Experiment 2

There were two analytical components to the second experiment: 1) analysis of the photos taken by game cameras and 2) the morphological properties of trampling damage. After six weeks of monitoring, the four game cameras positioned at each test area took a total of 20,296 photos. After careful inspection of each, a mere 3,114 (~15%) revealed ungulates within the test plot boundaries and only 43 showed actual hoof-to-bone interaction (Table 3.6). Most of the photos did, however, show animals near the plot

and were highly suggestive of trampling activity. The cameras also recorded the presence of local geese, turkeys, captive cranes, raccoons, coyotes, foxes, and a few unidentifiable small mammals. The only evidence of local carnivores directly interacting with the experimental remains resulted in the loss of one bone in Assemblage 3 to scavenging. This brought the total sample size down from 24 to 23 long bones. The use of camera traps also revealed the variability on non-domesticated ungulate behavior. While no other element was completely lost during the experiment, many were moved out of the test areas by the captive animals. Besides simply trampling over the assemblages, the herds would move the bones by kicking or pushing with their snouts and, in some cases, picking them up with their mouths (Fig. 3.4). The later of these actions was only observed with the giraffe in the 12-acre enclosure. Here ungulate chewing resulted in the movement, fracturing, and cortical modification of bones (Fig. 3.5).

Table 3.6: Summary of animal activity recorded during experiment 2

Assemblage/plot #	# of total photos per assemblage (recorded activity)	# of photos of ungulates in plot per assemblage	# of direct hoof-to-bone photos
1	2,736 (13%)	394 (13%)	13
2	1,477 (7%)	1,066 (34%)	7
3	14,926 (74%)	968 (31%)	22
4	1,157 (6%)	686 (22%)	1
Total	20,296 (100%)	3,114 (100%)	43(100%)

Table 3.7: Number of conspicuous trample marks per assemblage from experiment 2

Assemblage/plot #	Sediment type	# of conspicuous trample marks
1	Medium Angular	405 (59%)
2	Fine Angular	104 (15%)
3	Mixed Rounded	45 (7%)
4	Large Angular	134 (19%)
Total		688 (100%)



Figure 3.4: Variable behavior in non-domesticated ungulate herds. Buffalo sniffing/moving bones with snout (a) and Eland fighting over plot (b).

Of the 23 bones analyzed after six weeks of ungulate trampling, an estimated 688 conspicuous marks could be identified by the naked eye under strong light (Table 3.7). Both sediment type and animal activity had observable effects on the condition of retrieved elements. Thus, while the largest angular sediments might be expected to have generated the most abrasive damage, the relatively minimal activity over this plot produced only 19% of the recordable etchings. Similarly, despite have the most overall ungulate activity and being the runner-up for in-plot activity, assemblage 3 presented with the fewest discernable trample marks. The most commonly observed trampling damage in all assemblages, regardless of mark abundance, presented as groups of shallow, roughly parallel striations. When abundant, these abrasions often appeared in linear fields oriented obliquely or perpendicularly to the bone axis. Groove trajectories varied from straight, to curvy, to sinuous, and typically presented with asymmetrical shoulders. Whether or not the damage displayed as parallel fields, the association with intersecting striations, especially microabrasion, was common (Fig. 3.6).

Not all bones presented with an abundance of damage. While not as common as clusters of trample marks, individual striations of varying depth, length, and trajectory were observable. In most cases when grooves were present, internal microstriations were abundant. Similarly, shoulder effects, defined as “linear striations occurring no farther than 0.2 mm away from the groove edge”, were easily discernable within the parallel fields of damage (Domínguez-Rodrigo et al., 2009) (Fig. 3.6). Other forms of damage included the rare occurrence of barbs as well as variable pitting (Fig. 3.7). Pits presented as circular and rectangular gouges (not deep enough to be considered punctures) and occasionally had tapering tails. They were sometimes found singularly within a field of linear striations or in small clusters of their own. Barbs, however, were rare, only occurring once as is observed in figure 3.7. In addition to the observed cortical damage, four bones were heavily fragmented. One of these was from Assemblage 4 and likely resulted from buffalo trampling (Fig. 3.6). The three others were from Assemblages 1 and 2 and were likely the result of giraffe dropping them out of mouth from standing height (roughly 15 ft.) on a rocky surface (Fig. 3.5). These fragments were sometimes found more than 30 meters away from the test plot and often took more than a day to find. Thus, not all elements in this enclosure had 100% monitoring.

Experiment 3

The replication of methods advocated in Domínguez-Rodrigo et al. (2009) produced unexpected results. From a sample of 137 fragments only 17 were incised with conspicuous etchings viewable without the aid of magnification. A conspicuous mark is defined here as it is in the 2009 article stating that it must be “noticeable to the naked

eye” (Domínguez-Rodrigo et al., 2009). Thus, the identification of this damage was aided by strong light only. From the 17 incised bone fragments a total of 22 marks were distinguished, only three of which exceeded 5 mm in length. There was only a small difference in outcomes between the 10-second and 2-minute trampling durations and, besides the finest rounded sediment sample, there was little correlation between grain size and induced damage (Table 3.8). Once the noticeably damaged bone fragments were inspected under magnification, a variety of morphological features were perceptible.



Fig 3.5: Evidence of ruminant osteophagia. Image a) depicts an adult Masai giraffe chewing on radius (photo by Adrian Boyer), while b&c) show the damage observed on bone fragment presumably chewed by giraffe. Scale in photo (c)=1 cm.

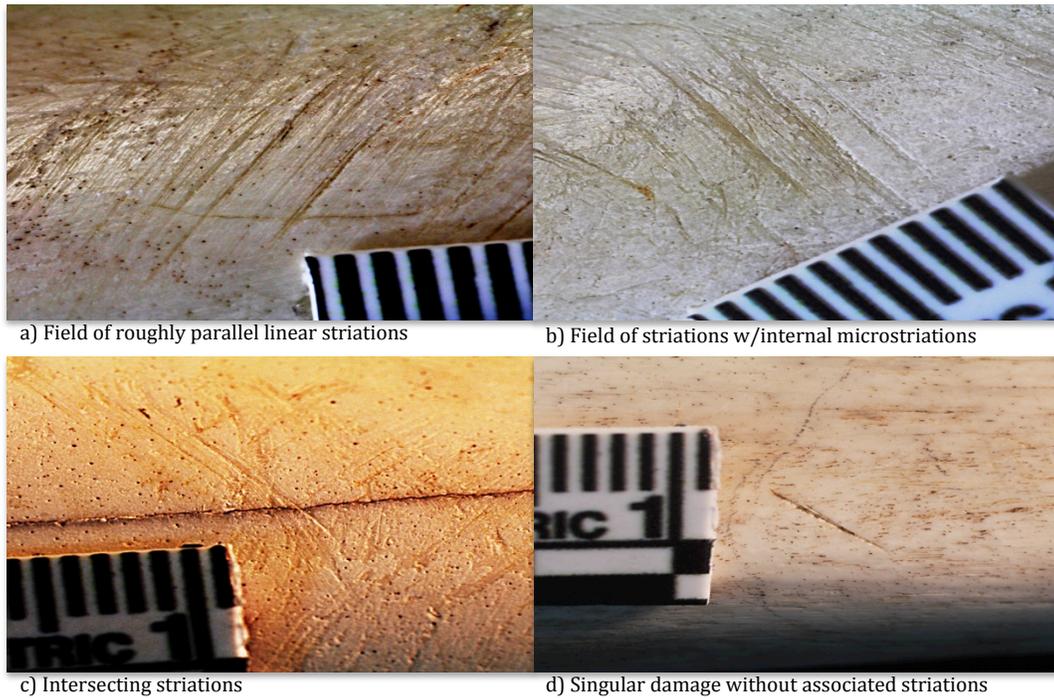


Figure 3.6: Most commonly observed trampling damage from experiment 2. Includes fields of shallow striations with shoulder effects, parallel arrangements, and occasional singular marks.

Microabrasion was the most common of these modifications, occurring in disorganized groups of curvy roughly linear streaks (Fig. 3.9). There were only three marks that resembled the damage produced in the prior experiment in length, appearance of microstriations, and/or association with fields of linear striations (Fig. 3.9). Otherwise, the most common conspicuous marks were short, sinuous and lacking internal striations (Fig. 3.8). These were closest in appearance to the pitting damaged observed above.

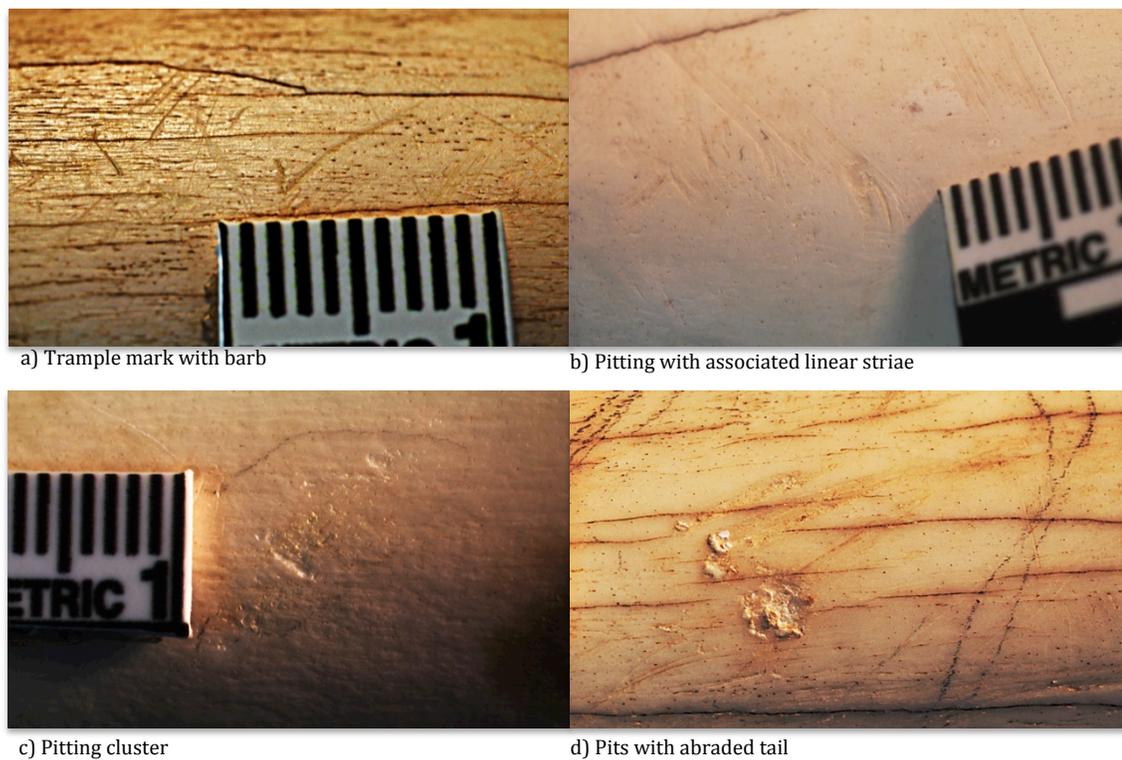


Figure 3.7: Presence of barbs and pits in trampled assemblages from experiment 2.

Table 3.8: Account of damage from experiment 3 defined as the number of trample marks per bone fragment per sediment type and duration.

<i>Sediment type</i>	<i>10-second duration</i>	<i>2-minute duration</i>	<i>Total # of marks</i>
<i>Assemblage 1</i>	2	4	6
<i>Assemblage 2</i>	5	3	8
<i>Assemblage 3</i>	1	0	1
<i>Assemblage 4</i>	2	5	7
<i>Total</i>	10	12	22

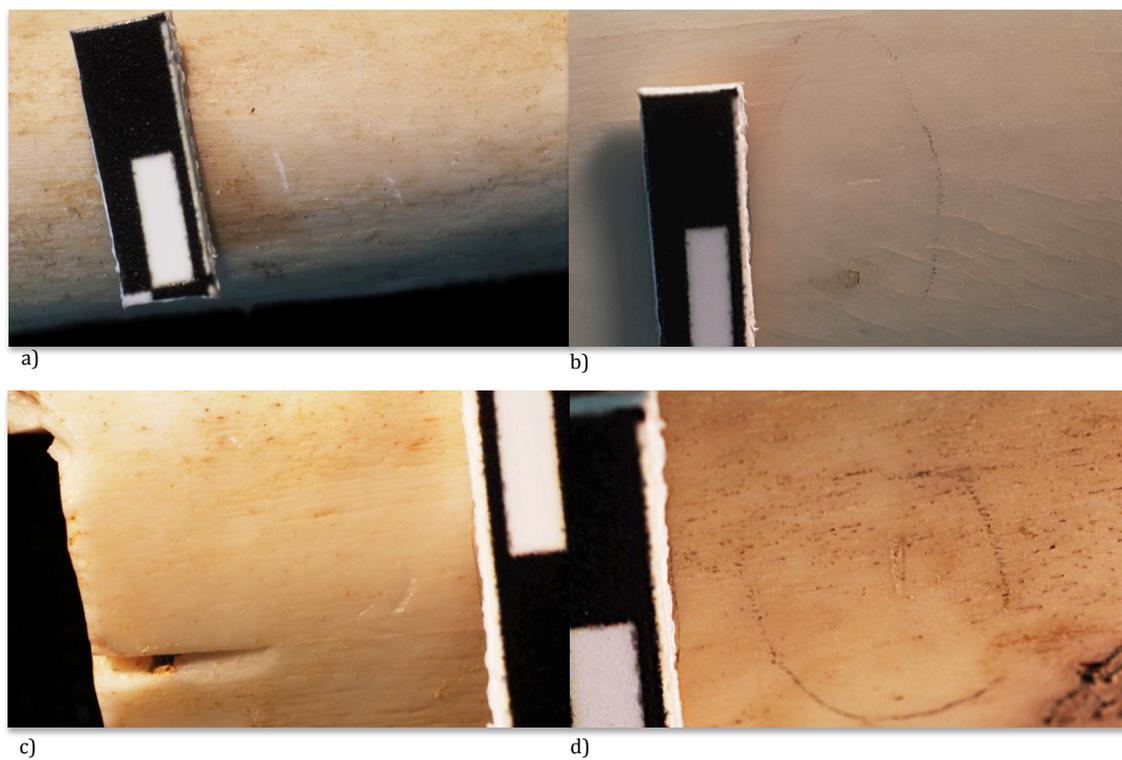


Figure 3.8: Short incisions (<5 mm) lacking internal microstriations and associated microabrasion. Photo a) comes from the 10 second duration, Sediment Type 2, b) comes from the 2 minute duration, Sediment Type 2, c) from the 2-minute duration, Sediment Type 4, and d) from the 2-minute duration, Sediment Type 1. Scale=1 cm.

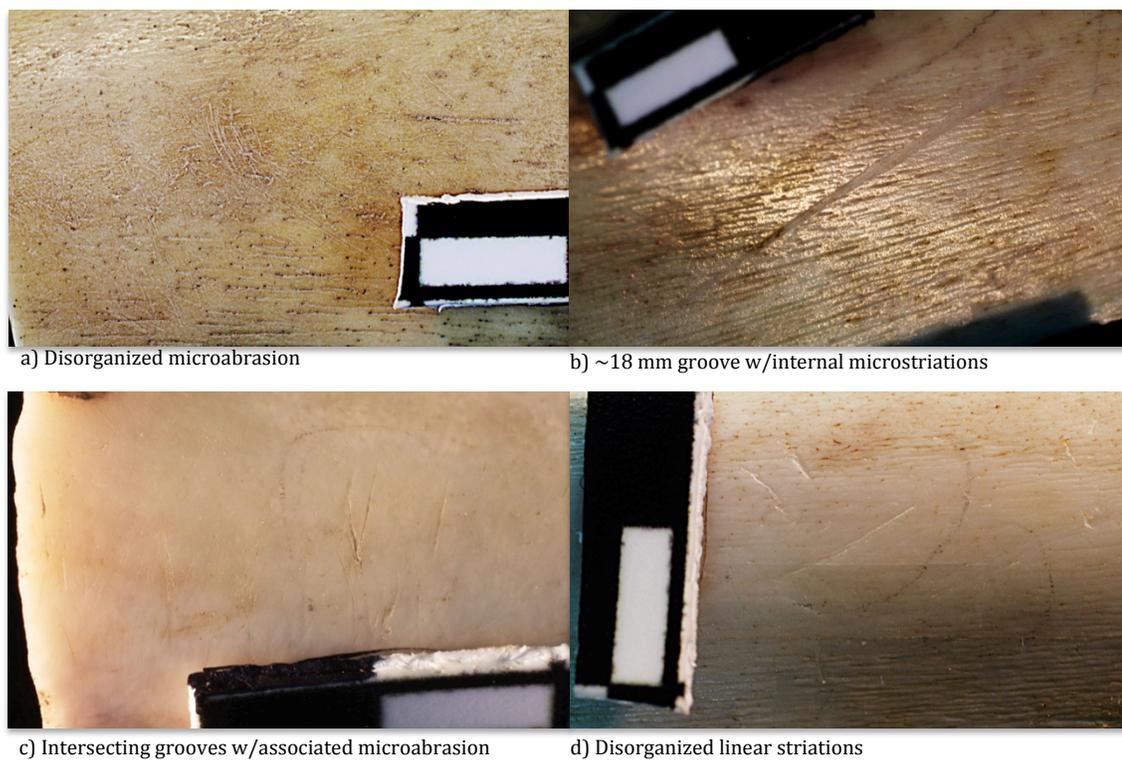


Figure 3.9: Photo a) comes from the 2-minute duration, Sediment Type 3, b) from the 10-second duration, Sediment Type 1, c) from the 2-minute duration, Sediment Type 1, and d) the 2-minute duration, Sediment Type 4. Scale=1 cm

CHAPTER FOUR:

UNGULATE BEHAVIOR AND TAPHONOMIC AGENCY

This series of experiments was developed for the purpose of comparing our current understanding of trampling taphonomy with damage produced under actualistic conditions. Broken into three distinct phases the results presented above account for the efficacy of game cameras as an experimental tool (experiment 1), cortical bone abrasions generated from ungulate trampling in variable sediments (experiment 2), and cortical bone abrasions generated from non-intensive human trampling in variable sediments (experiment 3). From them we were able to analyze two experimental skeletal assemblages, generated under different taphonomic conditions, side by side.

The results of experiment 2, which subjected four skeletal assemblages to six weeks of semi-wild ungulate trampling, revealed a variety of morphological traits that both coincide with and contrast data from previous research. The most commonly identified of this damage was in accordance with what was defined by Behrensmeyer et al. and Fiorillo as clusters of parallel, or sub-parallel shallow striations. Similar definitions come from the work of Olsen and Shipman and Domínguez-Rodrigo et al. but are difficult to gauge. The inclusion of humanly trampled bones in this experimental series provided an insight to how discreet these marks might have been. As opposed to the damage produced in experiment 2, the bone fragments from experiment 3 bore such shallow striations that they were barely discernable without the use of magnification. The fields of striations observed in the later series were distinctly different from this. While certainly shallow when compared to the deep gouges expected from chop marks and cut

marks, they were explicitly noticeable and even palpable when the bone surface was cleaned.

Before going too much further it is important to call attention to the disparities observed between the results of experiment 3 and those documented in Domínguez-Rodrigo et al. (2009). It is surprising from our experiment that the 2009 article identified a total of 251 conspicuous trample marks. While their sample size (220 fragments) was noticeably larger than what was used here (137 fragments), this discrepancy does not account for the vast differences in mark accumulation. Further, of the 22 conspicuous abrasions produced by human trampling agents in experiment 3, only 9 occurred in association with another. Only once were there more than two conspicuous marks observable across a single fragment and, of these, a mere 7 of the humanly generated trample marks measured more than 3 mm in total length (Fig.4). While the 2009 article does include groove length as one of their measured variables, there is no account this measure from their sample.

The conditions responsible for this inconsistency are not understood at this point but could involve the methods of analysis or experimentation. The account of humanly trampled remains attempted here only explicitly deviated from the former's methods in sample species, sample size, and sediment types. Our sediments, being the most noticeable deviance, would be surprising as a limiting factor since they were mostly larger and more angular than what was reported in the comparable research. It is similarly unlikely that the use of impala instead of deer would impact the results of this study. There are, however, potential differences between the two methodologies that would have occurred unintentionally. Specifically, it was not clear how long the authors of the

previous study boiled their bone fragments before trampling them or how heavy the trampling agents were. Thus, these measures were chosen subjectively.

The maximum 45-minute boiling time was specifically designated to keep from altering the structural integrity of skeletal tissue. When cooked (boiled or roasted), the collagen component of bone is denatured, leading to an established decrease in strength and stiffness. Experiments developed around this knowledge have proven that after boiling, bones are far more easily incised by abrasive action (Nicholson, 1992). While this period did not clean the bones to the point of whitening, the 45-minute duration appeared to be sufficient to clean off the adhering soft-tissue. Thus, in keeping the cook-time to a minimum we assume that the affects of trampling thoroughly boiled bone are not significant to our results. This, however, may have played a role in the considerable abundance of conspicuous abrasions observed by other authors. Concerning the weights of trampling agents, the individuals used here are admittedly light, with the heaviest of us weighing in at a mere 160 lbs. (~72.5 kg). Despite the minimal mass of trampling agents, the activity was done vigorously with the intention of producing significant etchings and therefore surprising if the discrepancy is entirely due to size. Nonetheless, the lacking abundance of trampling damage on previous studies has likely influenced the analytical approach observed in trampling taphonomy.

The regular occurrence of barely discernable trampling marks in previous works may be responsible for the heightened emphasis on solitary abrasion analysis and the use of SEM technology for microscopic investigation. Both Behrensmeyer et al. and Domínguez-Rodrigo et al. make mention of the likelihood for trample marks to occur on their own. It is argued from this that the identification of a standalone trampling mark

could lead to a misdiagnosis of butchery and therefore require careful analysis of discreet traits. The occurrence of individual marks was noticed in some capacity from the ungulate encountered assemblages examined here. Despite this, the complete absence of adjacent incisions on the trampled bones was rare. Thus, only three of the twenty-three bones analyzed bore less than ten conspicuous marks and only eleven had less than twenty. While it is true that a bone fragment bearing one of these marks could lead to a misdiagnosis of butchery damage, their rare occurrence suggests that a broader inspection of multiple elements would reveal evidence more in line with ungulate trampling. Such a finding would shed light on the history of the entire assemblage leading any researcher to seriously consider trampling as the root cause for most, if not all, damage identified in the rest of the sample. Hence, identification of a single bone bearing evidence of trampling will imply that trampling occurred over the majority of the assemblage. When examining trampling abrasions under magnification, however, solitary incisions did exhibit qualifying characteristics typically attributed to cut mark morphology.

Some of the most diagnostic criteria used for assessing potential cut marks have been focused on individual grooves. Qualities such as groove trajectory, internal microstriations, shoulder flaking and symmetry, as well as shoulder effects and barbs have all been defined and used as distinguishing features. Of these morphological indicators, the only thing not seen in the ungulate driven trampling sample was shoulder flaking. This trait is defined by Domínguez-Rodrigo et al. as “a continuous series of exfoliation of the shoulder edge” and was determined by them to be mostly absent from trampling marks (2009). Importantly, this feature was also uncommon in cut marks made with un-retouched tools and appeared on barely more than 50% of the marks from

retouched tools, possibly disqualifying it as a discriminating variable. This is perhaps expected in such a fragile feature. Out of the many physical properties associated with cut marks, it is not difficult to imagine this particular feature to be susceptible to wearing from continuous abrasion. The likelihood of marks to lose their original form when trampled for prolonged periods was mentioned early on in trampling literature (Behrensmeyer et al., 1986), but was mostly applied to internal microstriations. Despite the six-week duration of this project, however, microstriae were far from uncommon in the observed damage. This finding is one that does align with much of the previous research, only contrasting the statements made by Olsen and Shipman (1988).

In pursuing a much higher intensity trampling experiment, Olsen and Shipman argued that the lack internal microstriations is a result of continuous abrasive actions wearing away the micro-morphology. This idea suited the findings of Behrensmeyer et al. and suggested that the appearance of trampling damage would depend on the intensity and duration of stress. While the absence of microstriations within the cavity of primary grooves was not as noticeable here, the presence of bone pitting was. These pits were almost always found associated within larger fields of damage and appeared as circular or oblong gouges no more than a couple of millimeters in diameter. Their appearance is indicative of single grains being directly impacted into the bone cortex instead of simply abrading across it. These grains would then either fall off leaving the circular appearance or be sloughed off slightly abrading the bone after their initial impression.

Other notable features, such as shoulder asymmetry and shoulder effects were more common. These were mostly observed within the fields of parallel or sub-parallel etchings. Finally, the orientation and trajectory are given much credence in the literature.

The orientation of marks was as diverse as has been suggested in previous works. Where they were abundant, trampling marks often intersected at oblique angles and ran mostly perpendicular and obliquely to the bone's axis. Groove trajectory, however, was more difficult to discern. While many of the marks could be determined as curvy from a macroscopic perspective, distinguishing between sinuous and straight required a highly magnified view. Thus, most of the marks that appeared to be straight to the naked eye would later be defined as sinuous when enhanced. For this reason, our results coincide with results of the aforementioned research but bring to attention a potential problem in current taphonomic research.

The use of Scanning Electron Microscope (SEM) in trampling research has been a part of most analysis since the 1980's. With this instrument researchers were able to enhance the view of the slightest of abrasive marks and, thus, be able to discuss otherwise unobservable features. The use of SEM has therefore advanced our understanding of abrasive bone modification significantly. However, as we continue to compare the damage produced by trampling and butchery, these advances are possibly become less useful. With the commonality of internal striations and the variability of cross-sectional morphology, SEM analysis might obfuscate cortical damage more so than elucidating it. Thus, from a reader's perspective, the intensive magnification of bone modification confuses the inherent qualities of that mark. This is especially true if the author chooses specific sections of an incision to represent their point. If, for example, the abrasions in figures 8 or 9 were magnified enough, they would potentially appear more complex and potentially significant. Thus, not able to confidently discern the relative length and depth

of a groove, it is easy to mistake a barely visible and unconvincing mark for one that is truly well formed and indicative of a particular diagnostic feature or action.

As considered earlier, the aforementioned reliance on single mark analysis and advanced microscopy likely has to do with the minimal amount of damage produced in humanly trampled experimental assemblages. Further, as seen with the Domínguez-Rodrigo et al. replication, humanly trampled bones differ significantly in appearance than those bearing ungulate driven damage (2009). This seems to be true also of the longer term, intensive human trampling seen in Olsen and Shipman (1988). The reasons for this will almost assuredly involve the size and anatomical differences of humans and herd animals, but may also reflect important behavioral parameters previously unconsidered.

To label trampling as the particular taphonomic activity in question is maybe insufficient in explaining the extent of ungulate induced sedimentary abrasion. Though observations of domestic animals such as cattle, sheep, and goats, could lead one to think that ungulates are fairly homogenous in behavior, the world's wild herds are far more dynamic than those seen in ranches or other pastoralist circumstances. In natural settings such gregarious animals manage complex intraspecific social structures and mediate interspecific territorial and predatory interactions, as well as the expected resource driving migrations. While the fundamental action of treading over death assemblages remains the same in many cases (i.e. element compression against abrasive sediments) this myriad of behaviors might have profound impacts on the bones interacted with, thus producing damage otherwise unseen when experimentally replicated.

The use of camera traps for this project was highly informative and should be considered in future trampling discussions. From them it first became apparent that,

contrary to that suggested by Olsen and Shipman (1988), these animals made no effort whatsoever to avoid stepping on any of the bones in their path. In fact, soon after the start of the project most of the wildlife seemed mostly oblivious to the assemblages. The first weeks, however, were different. As a novel addition to the enclosures, many animals frequented the assemblage sites. The most typical behavior during this time was to sniff the remains, moving them within and out of the test plots with their noses. This was especially common with the buffalo, forcing us to reset Assemblage 4 multiple times during the first week. Similar difficulties were experienced with the assemblages in the giraffe enclosure but for different reasons.

It is not uncommon for large ruminant animals to chew on bones found within their environment. Known as Osteophagia, this phenomenon is explained as a means of acquiring particular nutrients not abundant in herbivorous diets and to maintain comfortable phosphorous/calcium levels (Hutson et al., 2013). Despite this research, the thought that giraffe might collect and gnaw on the elements from this experiment did not factor into methodological considerations. Giraffe did, however, have a considerable impact on some these bones. While cortical damage was realized on some fragments (Fig. 5a), these abrasions were distinct enough to not obscure the taphonomic analysis. The larger complication that arose from this action was the horizontal displacement of bones across the twelve-acre enclosure. As mentioned in chapter four, this limited the ability of the game cameras to account for all of the stress placed on these bones. These interests exhibited by the giraffe also lead to bone shattering. Three of the 12 bones in the giraffe enclosure were completely shattered by the end of the project. While not each of these events was explicitly witnessed, on one occasion a giraffe was observed dropping a

bone from its mouth (roughly 4 m off the ground) onto the rocky surface below. Thus, the impact of the bone hitting an underlying rock resulted in destruction of the element. Thus, it might be considered that such impact trauma has the potential to mimic the percussive damage discussed in marrow extraction strategies of hominins. This, however, is purely conjecture and would require serious research before being advocated in any way more than casual interest.

Beyond the anomalous instances of ruminant osteophagia, typical trampling damage is very much the effect of forceful deposition. Opposing the suggestion that this act is simply another example of sedimentary abrasion, the current research suggests that the behaviors involved in ungulate trampling have a specific value in inducing cortical damage (Olsen and Shipman, 1988). Besides the mundane occurrence of casually stepping on bones, herd animals impact the underlying matrix at variable speeds and trajectories. It is entirely feasible to assume that, based on the commonality of fields of obliquely angled parallel grooves, trampling damage occurs in highly dynamic circumstances. Such circumstances are substantially different than the one-dimensional action of downward compression. Thus, replication of this action must prove to be similarly dynamic.

Photographic evidence gathered from this experiment elucidated this idea by displaying such actions as male-male competition and of chase across many of the test areas (Fig. 4b). If, during this time, the animals involved stepped directly on one of the bones they would be placing on it a stress load unlike that of a casual trot or a stomp. This is due to the force needed to propel a large animal at rapid speeds or while opposing an equal or greater force during competition. Contrastingly, these cameras also

documented numerous instances of large animals lying, relatively immobile, directly over the test assemblages. This is also in opposition to previous considerations of ungulate induced abrasion that suggested sustained stress would be unlikely (Olsen and Shipman, 1988). While not as dynamic a force as active trampling, prolonged pressure placed over skeletal assemblages will almost certainly factor into the damage produced across the cortical surfaces. This is especially true if the animals move even the slightest bit when resting. Here this was most often witness with animals weighing over 1000 lbs.

While there is no question that the use of cameras was informative, it is important to note that there were difficulties involved. These arose mostly in the previously discussed enclosures housing assemblages 1 and 2 and concerned the placement of cameras and unrelated animal activity. Assemblage 1 was positioned in the middle of the twelve-acre exhibit. Its placement was chosen due to the high animal traffic observed there by Safari West staff and for its proximity to a structure sufficient for camera placement. This structure, however, was limited vertically and required the camera to be secured only a couple of feet off of the ground. The effects of this were variable. While it still served to track the movements of all nearby animals, many of the large ungulates would stand near enough the lens to obscure a useful view of the test area. Since animals were not documented as standing in the sample area with out direct observation, these obstructed views likely biased the data in table 3.6. Further, being within range for physical contact for all animals in this enclosure, the camera over Assemblage 1 was occasionally contacted and displaced, requiring it to be repositioned and causing momentary lapses in data collection. Despite the higher camera positioning, this would

also occur at Assemblage 2, though to a much lesser extent. This was merely a complication of working around giraffe.

The other complication experienced in this enclosure directly effected the amount of photos taken at both plots (Table 3.6). Again effecting Assemblage 1 more than Assemblage 2, the many East African Crowned Cranes kept in this enclosure showed great interest in the cameras and the plots. While they did not interact much with the scattered bones, the birds' interest in both cameras and sediments resulted in an immense amount of experimentally useless photos. Thus, the notable discrepancy at Assemblage 1 between "number of photos" and "number of photos with ungulates in plot" is mostly the effect of overly interested cranes. While this had little impact on the results of the study, it was a tiresome inconvenience when analyzing photographic data. In all, however, the use of camera traps proved to be a valuable addition to this research, successful in assuring that the observed skeletal damage occurred from trampling actions and providing insight into behavioral patterns leading to it.

CHAPTER FIVE:

CONCLUSION

Taphonomic analysis is the foremost method for assessing human behavior in Plio-Pleistocene fossil deposits. Distinguishing between the causes of various forms of cortical abrasion, however, can be difficult and lead to faulty claims if the observer is not careful. Despite this difficulty, tremendous effort has been put into deciphering the myriad of taphonomic signatures. This is due to the significance of the questions involved in these studies. The point in which the hominin line began consuming meat and manufacturing tool industries marks the moment in which they might be considered behaviorally human. Discerning when and where this began to occur regularly then has dramatic effects on how we view the course of our evolutionary history. To accomplish this task, taphonomic analysis seeks to discriminate between human and non-human bone modifying forces. With proper analysis there is hope to determine instances of hominin carnivory and tool use without relying on the direct identification of scant and feeble stone tools.

While most taphonomic research has focused on the similarities and differences of carnivore induced dental damage and stone tool damage, the abrasions left on bone from ungulate trampling have generated interest enough for more than three decades of exploration. These decades of investigation have challenged researchers to conceptualize how it is that hoofed animals scar bone in a predictable way. Olsen and Shipman define trampling damage simply as a form of sedimentary abrasion (1988). Defining it as such infers an uncomplicated action induced by the downward force of hooves into angular sediments and presents this process as easily replicable. When this action is replicated in

unrealistic terms, however, it becomes apparent that numerous variables demand consideration and that even slight methodological adjustments produced different abrasive outcomes. Thus, it was not the intent of this project to categorize the specific criteria needed to diagnose trampling damage in the fossil record. Instead, it was designed to reveal the variability inherent in this taphonomic action and to highlight the limitations of previous research.

The consideration of animal behavior in taphonomic research has proven to be of great significance. This, of course, seems obvious when defining biotic taphonomic damage as the result of behavior, but has received little attention in most studies not focused on butchery practices. Animals of all types interact with their surroundings in different ways. Thus, ungulates may play, fight, sleep, or walk over skeletal assemblages just as different predators have unique hunting/killing strategies (i.e. crocodilian death roll). Further, as has been popularized with elephants, some herbivorous animals may intentionally interact with bones found in their path. This could result in simply moving the remains within a small area or even chewing on them with abrasive and fracturing consequences. Though not all behavioral patterns are going to mar bones in distinct ways, insight into how animals behave should be a part of experimental practices.

The use of semi-wild ungulate herds in this project had a noticeable effect on the manifestation of cortical abrasion producing distinctive differences between the humanly trampled and ungulate trampled bones. The depth, length, association and abundance of scars were all greater in the actualistic sample, creating an appreciably altered assemblage. This finding, however, suggests that trampling damage may be more easily identified in fossil contexts. Further, given the variability of trampling damage, the

identification of these common indicators should call into question any other damage found in an assemblage. Since low abundance marks were confirmed as an occasional effect of trampling, this suggestion encompasses the discovery of solitary gouges. Thus, I recommend that such scrutiny be included in the configurational approach to potential archaeological sites.

It is now apparent that the use of human agents in trampling experimentation is inadequate for producing the damage likely to be found in fossil assemblages. This is due to the fact that, while unable to be proven, the likelihood of humans intentionally stomping on bones in a confined space during the Pliocene and Pleistocene epochs is slim. Ungulate trampling, however, is an expected and lively process that may alter the appearance of bones in many ways. Particularly in Africa, gregarious ungulates range in size from roughly 60 kg to over a ton, and may roam in herds numbering in the millions. Contrary to our domestic herds, these animals live dynamic lifestyles that require them to negotiate complex social environments while also constantly mediating predatory interactions. This requires them to maneuver in ways that are difficult to imitate. The resources made available for the current study, however, allowed for a closer look at how trampling damage actually occurs and will hopefully add to our ability to confidently read the fossil record.

From an experimental standpoint, this project developed a new methodological approach to ungulate driven taphonomy. The resources available at zoological institutions are not unknown to those interested in bone modification and should be used whenever possible. Further, game camera technology is readily available and can solve many of the procedural problems that have been observed in the past.

REFERENCES

- Andrews, Peter, and Jill Cook
 1985 Natural modifications to bones in a temperate setting. *Man*:675-691.
- Behrensmeier, Anna K.
 1978 Taphonomic and ecologic information from bone weathering. *Paleobiology*:150-162.
- 1984 Non-human fracturing and surface damage in Miocene bones with notes on related taphonomic experiments. First International Conference on Bone Modification, Carson City, Nevada, pp. 3-4.
- Berger, Lee R., et al.
 2010 *Australopithecus sediba*: A new species of Homo-like australopithecine from South Africa. *Science* 328(5975):195-204.
- Blasco, Ruth, et al.
 2008 A new element of trampling: an experimental application on the Level XII faunal record of Bolomor Cave (Valencia, Spain). *Journal of Archaeological Science* 35(6):1605-1618.
- Boesch, Christophe, and Hedwige Boesch
 1982 Optimisation of nut-cracking with natural hammers by wild chimpanzees. *Behaviour*:265-286.
- 1984 Mental map in wild chimpanzees: an analysis of hammer transports for nut cracking. *Primates* 25(2):160-170.
- 1990 Tool use and tool making in wild chimpanzees. *Folia primatologica* 54(1-2):86-99.
- Boesch, Christophe, et al.
 1994 Is nut cracking in wild chimpanzees a cultural behaviour? *Journal of Human Evolution* 26(4):325-338.
- Borrini, M., et al.
 2012 Contextual taphonomy: superficial bone alterations as contextual indicators. *Journal of Biological Research-Bollettino della Società Italiana di Biologia Sperimentale* 85(1).
- Brain, Charles K.
 1967 Bone weathering and the problem of bone pseudo-tools: Namib Desert Research Station.

- Brain, Charles Kimberlin
1981 The hunters or the hunted?: University of Chicago Press.
- Braun, David R., et al.
2010 Early hominin diet included diverse terrestrial and aquatic animals 1.95 Ma in East Turkana, Kenya. *Proceedings of the National Academy of Sciences* 107(22):10002-10007.
- Breuil, Henri, and Mary Elizabeth Boyle
1939 Bone and antler industry of the Choukoutien *Sinanthropus* site: Geological Survey of China.
- Bril, Blandine, et al.
2012 Functional mastery of percussive technology in nut-cracking and stone-flaking actions: experimental comparison and implications for the evolution of the human brain. *Philosophical Transactions of the Royal Society B: Biological Sciences* 367(1585):59-74.
- De Heinzelin, Jean, et al.
1999 Environment and behavior of 2.5-million-year-old Bouri hominids. *Science* 284(5414):625-629.
- Domínguez-Rodrigo, Manuel
1997 Meat-eating by early hominids at the FLK 22 *Zinjanthropus* site, Olduvai Gorge (Tanzania): an experimental approach using cut-mark data. *Journal of human Evolution* 33(6):669-690.
- Domínguez-Rodrigo, Manuel, Henry T. Bunn, and José Yravedra
2013 A critical re-evaluation of bone surface modification models for inferring fossil hominin and carnivore interactions through a multivariate approach: Application to the FLK Zinj archaeofaunal assemblage (Olduvai Gorge, Tanzania). *Quaternary International*.
- Domínguez-Rodrigo, Manuel, et al.
2009 A new protocol to differentiate trampling marks from butchery cut marks. *Journal of Archaeological Science* 36(12):2643-2654.
- Domínguez-Rodrigo, Manuel, Travis Rayne Pickering, and Henry T. Bunn
2010 Configurational approach to identifying the earliest hominin butchers. *Proceedings of the National Academy of Sciences* 107(49):20929-20934.
-

2011 Reply to McPherron et al.: Doubting Dikika is about data, not paradigms. *Proceedings of the National Academy of Sciences* 108(21):E117-E117.

2012 Experimental study of cut marks made with rocks unmodified by human flaking and its bearing on claims of ~ 3.4-million-year-old butchery evidence from Dikika, Ethiopia. *Journal of Archaeological Science* 39(2):205-214.

Domínguez-Rodrigo, Manuel, et al.

2005 Cutmarked bones from Pliocene archaeological sites at Gona, Afar, Ethiopia: implications for the function of the world's oldest stone tools. *Journal of Human Evolution* 48(2):109-121.

Domínguez-Solera, Santiago, and Manuel Domínguez-Rodrigo

2011 A taphonomic study of a carcass consumed by griffon vultures (*Gyps fulvus*) and its relevance for the interpretation of bone surface modifications. *Archaeological and Anthropological Sciences* 3(4):385-392.

Domínguez - Rodrigo, Manuel, and Travis Rayne Pickering

2003 Early hominid hunting and scavenging: a zooarcheological review. *Evolutionary Anthropology: Issues, News, and Reviews* 12(6):275-282.

Efremov, Ivan A.

1940 Taphonomy: a new branch of paleontology. *Pan-American Geologist* 74(2):81-93.

Ferraro, Joseph V., et al.

2013 Earliest archaeological evidence of persistent hominin carnivory. *PLoS one* 8(4):e62174.

Fiorillo, Anthony R.

1984 An introduction to the identification of trample marks. *Current Research in the Pleistocene* 1(4).

1991 Taphonomy and depositional setting of Careless Creek Quarry (Judith River Formation), Wheatland County, Montana, USA. *Palaeogeography, Palaeoclimatology, Palaeoecology* 81(3):281-311.

Gaudzinski-Windheuser, Sabine, et al.

2010 Testing heterogeneity in faunal assemblages from archaeological sites. Tumbling and trampling experiments at the Early-Middle Pleistocene site of Geshen Benot Ya'akov (Israel). *Journal of Archaeological Science* 37(12):3170-3190.

- Gilbert, W. H., and G. D. Richards
2000 Digital imaging of bone and tooth modification. *The Anatomical Record* 261(6):237-246.
- Hutson, Jarod M., Chrissina C. Burke, and Gary Haynes
2013 Osteophagia and bone modifications by giraffe and other large ungulates. *Journal of Archaeological Science* 40(12):4139-4149.
- Leakey, Louis S. B., Phillip V. Tobias, and John Russell Napier
1964 A new species of the genus *Homo* from Olduvai Gorge: na.
- Lyman, R. Lee
1987 Archaeofaunas and butchery studies: a taphonomic perspective. *Advances in archaeological method and theory*:249-337.
—
1994 *Vertebrate taphonomy*: Cambridge University Press.
- Lyman, R. Lee, and Gregory L. Fox
1989 A critical evaluation of bone weathering as an indication of bone assemblage formation. *Journal of Archaeological Science* 16(3):293-317.
- Madgwick, Richard, and J. Mulville
2012 Investigating variation in the prevalence of weathering in faunal assemblages in the UK: a multivariate statistical approach. *International Journal of Osteoarchaeology* 22(5):509-522.
- Marean, Curtis W., and Zelalem Assefa
1999 Zooarcheological evidence for the faunal exploitation behavior of Neandertals and early modern humans. *Evolutionary Anthropology* 8:22-37.
- McKinley, Michael P., and Valerie Dean O'Loughlin
2006 *Human anatomy*: McGraw-Hill Higher Education.
- McPherron, Shannon P., et al.
2010 Evidence for stone-tool-assisted consumption of animal tissues before 3.39 million years ago at Dikika, Ethiopia. *Nature* 466(7308):857-860.
- McPherron, Shannon P., et al.
2011 Tool-marked bones from before the Oldowan change the paradigm. *Proceedings of the National Academy of Sciences* 108(21):E116-E116.
- Mercader, Julio, et al.

2007 4,300-year-old chimpanzee sites and the origins of percussive stone technology. *Proceedings of the National Academy of Sciences* 104(9):3043-3048.

Nicholson, Rebecca A.

1992 Bone survival: the effects of sedimentary abrasion and trampling on fresh and cooked bone. *International Journal of Osteoarchaeology* 2(1):79-90.

Njau, Jackson

2012 Reading Pliocene Bones. *Science* 336(6077):46-47.

Olsen, Sandra L., and Pat Shipman

1988 Surface modification on bone: trampling versus butchery. *Journal of Archaeological Science* 15(5):535-553.

Panger, Melissa A., et al.

2002 Older than the Oldowan? Rethinking the emergence of hominin tool use. *Evolutionary Anthropology: Issues, News, and Reviews* 11(6):235-245.

Reeves, Nicole M.

2009 Taphonomic Effects of Vulture Scavenging*. *Journal of forensic sciences* 54(3):523-528.

Ryan, Timothy M., and Colin N. Shaw

2012 Unique suites of trabecular bone features characterize locomotor behavior in human and non-human anthropoid primates. *PloS one* 7(7):e41037.

Semaw, Sileshi, et al.

1997 2.5-million-year-old stone tools from Gona, Ethiopia.

Shaw, Colin N., and Timothy M. Ryan

2012 Does skeletal anatomy reflect adaptation to locomotor patterns? Cortical and trabecular architecture in human and nonhuman anthropoids. *American journal of physical anthropology* 147(2):187-200.

Shipman, Pat, and Jennie J. Rose

1984 Cutmark mimics on modern and fossil bovid bones. *Current Anthropology* 25(1):116-117.

Van Schaik, Carel P., Robert O. Deaner, and Michelle Y. Merrill

1999 The conditions for tool use in primates: implications for the evolution of material culture. *Journal of Human Evolution* 36(6):719-741.

White, Tim D., Michael T. Black, and Pieter A. Folkens
2011 Human osteology: Academic press.

White, Tim D., and T. D. White
1992 Prehistoric cannibalism at Mancos 5MTUMR-2346: Princeton
University Press Princeton.

Wynn, Jonathan G., et al.
2006 Geological and palaeontological context of a Pliocene juvenile hominin
at Dikika, Ethiopia.