Spatial approaches to site formation and carnivore-hominin interaction at Dmanisi, Georgia

A DISSERTATION
SUBMITTED TO THE FACULTY OF THE
UNIVERSITY OF MINNESOTA
BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

ADVISER: Dr. Martha Tappen

JUNE 2016

ACKNOWLEDGEMENTS

to work with in the museum and I will forever remember our many trips to the khinkhali house!

My graduate career was also enhanced by the guidance of both Kieran McNulty and Gilbert Tostevin. They provided excellent comments on my prelim and dissertation papers and I will always admire their wealth of knowledge of our discipline. I am also grateful for the lab help I received over the years from John Soderberg, Keith Manthie, and Matt Edling. Much of my work could not have been completed without their assistance.

It has been a long, long process getting the breakage paper ready for publication and I am thankful to Katrina Yezzi-Woodley for being there to get us all through. I am indebted to her dedication to the project and her clarifications on statistics and R code. She has been a pleasure to work with and I look forward to where the breakage experiment takes us!

My knowledge of the history of Dmanisi excavations and archaeology was shaped in an unforgettable way by Teona Shelia, David Zhavania, Gocha Kiladze, Giorgi Kopaliani, Jimi Chkhvimiani, Giorgi Bidzinashvili, Giorgi Chochishvili, Ani Margvelashvili, Nika Tsikaridze, Nana Rezesidze, Khatuna Gaprindashvili, Sophio Panchulidze, Medea Nioradze, Mark Furio, Acho Khachapuridze, Sopho Kiladze, Adam van Arsdale, Philip Rightmire, Jordi Agusti, and so many others.

A graduate school experience is only as good as the people around you, and the graduate students at the University of Minnesota are some of the greatest people I have ever known. From serious conversations about research and collaborations to not-so-serious conversations about everything else, I am thankful for the following people for

keeping me sane and entertained while building unforgettable relationships: Aaron Armstrong, Kirsten Jenkins, Austin Jenkins, Linda Chisholm, Burton Smith, Rebecca Nockerts, Sam Porter, Rutger Jansma, Ryan Knigge, Jason Massey, and many others. I am forever shaped for the better because of all of you.

I am incredibly humbled to be married to Katherine Erdman, who has been a constant source of support and inspiration throughout graduate school. Seeing her navigate her way through graduate school was truly amazing to watch and I am incredibly proud to share my life with her. I am beyond excited for all of our post-graduate school adventures to come!

Lastly, I am the person I am today because of my family, and especially my parents. They have encouraged me throughout my life to pursue what makes me happy and the support never ceases. They are selfless and amazing, and I could not have done this without them. My brother has also been wonderfully supportive, though it took him several years to realize I was not studying cryptozoology! He always keeps me grounded and I am grateful for that.

DISSERTATION ABSTRACT

       Spatial analyses are valuable tools for examining abiotic and biotic site formation processes that contribute to the accumulation of archaeological and paleontological material. When these analyses are used in tandem with taphonomic and geologic interpretations, archaeologists can make stronger arguments for site reconstruction and behavioral inferences. Spatial analyses have been used for decades to understand how human behaviors and the deposition of material are linked. Similarly, spatial behaviors by carnivores are apparent, with some species, namely hyenas, differentially using space for various behaviors. Through the lens of spatial analysis, this dissertation examines the degree to which abiotic and biotic agents contributed to site formation at the Early *Homo* site of Dmanisi, Georgia.

       Taphonomic and geologic studies at Dmanisi have interpreted the hominin-bearing deposits in Block 2 as resulting primarily from biotic agents, mainly carnivores, and not from fluvial or colluvial action (Lordkipanidze et al., 2006, 2007; Tappen et al., 2007). This dissertation expands on these interpretations by providing spatial evidence from two excavation areas (M6 and Block 2) and multiple strata used in conjunction with taphonomic analyses by Martha Tappen and geologic and archaeological analyses by Reid Ferring to compare relatively horizontal strata to the complex pipe/gully fill strata in which the highest concentration of bones are found. Orientation and dip, fragmentation and winnowing, and skeletal refits are examined and the results for each support the interpretation that the assemblages are not a product of fluvial and colluvial deposition.

What is more, an analysis of spatial patterning indicates that higher densities of carnivores are located in the pipe/gully fill deposits than elsewhere. Also, coprolites are prevalent in these deposits, but follow a different spatial distribution than the skeletal material. Taphonomic analyses demonstrate that carnivores contributed greatly to the consumption of carcasses, and several species of carnivores are present at Dmanisi during this time. Each species of hyena has been observed to defecate in specific areas, both inside of the dens and outside in latrines, which could explain the cluster of coprolites in the B1 strata in Block 2. Two of the pipe/gully fill phases of B1 (B1x and B1y) are within a complex basalt formation that could have provided a secluded area for carnivores to consume carcasses and potentially have dens. These coprolites provide potential insight into carnivore space use in the Early Pleistocene, but further analysis is necessary to attribute the coprolites to specific animals. In any case, carnivores appear to be the main influence on site formation at Dmanisi, while the hominin imprint is minimal.

In order to understand the potential carnivore-hominin interaction and the timing of carcass access at Dmanisi, this dissertation also provides new analytical methodology for studying bone fracture angles produced during the marrow acquisition process. In lieu of agent-specific surface modifications (i.e. carnivore tooth marks or hammerstone percussion marks), green breaks on long bones are difficult to attribute to a specific agent of breakage. By quantifying fracture angles, perhaps archaeologists can infer the causal agent of breakage and interpret the influence of carnivores and hominins on bone breakage. This dissertation contributes the results of a controlled breakage experiment where bones were broken by hyenas and hammerstones. Based on the results of the fracture angle analysis, different long bones create different fracture angle assemblages

and it is necessary to identify the long bone fragments to at least limb portion (upper, middle, lower) if not to skeletal element. In addition, the preliminary results of the hyena created assemblage shows that hyena broken bones result in fracture angles further from 90° than hammerstone broken bones.

Carnivores played an important role in the accumulation of faunal material at Dmanisi, Georgia. Evidence for abiotic site formation processes, such as fluvial and colluvial deposition, is minimal and likely did not affect the original depositional context of the stones and faunal material. The hominin contribution to site formation is also minimal, but perhaps understanding fracture angles created during the marrow acquisition process can allow for further testing of this hypothesis in the context of Early *Homo*. By examining these different factors, this dissertation broadens the knowledge of how carnivores and hominins contributed to site formation during the earliest expansion of our genus outside of Africa.

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CHAPTER 1: Dissertation Introduction

Understanding the processes that contributed to the formation of archaeological sites is imperative for interpreting past human behavior. These processes, both biotic and abiotic, can accumulate large quantities of stones and faunal material, but do so in quite different ways. The processes themselves can be very different, but the resulting deposits often confound archaeologists because of equifinality, i.e. the same ends by different means. Fortunately for archaeologists today, strong frameworks have been created for sorting through these different depositional processes, which in turn aid in the accurate interpretation of the processes that contributed to the creation of archaeological sites.

Archaeological assemblages are identified as having material items and/or traces (e.g. artifacts, cut marked bone, etc.) relating to human behavior, but these materials are not always deposited by humans directly. Some carnivores and rodents accumulate bone in great numbers and even relocate bones after having secondary access to those already exhausted by humans. Abiotic factors also contribute to the re-deposition of hominin modified material. Fluvial and colluvial action can create large deposits over both short and long periods of time. Thus, archaeologists must consider both abiotic and biotic site formation processes prior to making a final interpretation of a site, even when evidence of human activity is present (Rick, 1976; Schiffer, 1983; Schiffer, 1987).

Taphonomic analyses contribute greatly to the understanding of depositional processes and supplement geologic interpretations of archaeological accumulations. Many formation processes leave specific traces on bones that reflect their depositional history. Fluvial transport can round the edges and abrade surfaces of bones

(Behrensmeyer, 1988). Sub-aerial weathering can alter the physical state of skeletal material on the ground surface, leaving bones cracked and flaked (Behrensmeyer, 1978). Carnivores, rodents, and other animals, including humans, leave marks from their teeth after gnawing bones. Humans create cut marks from butchery and percussion marks from marrow acquisition. Marks made by fungal etching and chemical diagenesis also occur and reflect the post-depositional, post-burial processes (Domínguez-Rodrigo and Barba, 2006). All of these modifications on bone are important indicators of site formation, but they should be used in tandem with other analyses to enhance these interpretations.

Spatial analysis informs broader questions about relationships between material and behavior and is an effective tool for locating large and small scale spatial patterns. In general terms, spatial analysis consists of two main approaches: Inter-site and intra-site. Inter-site spatial analysis focuses on the comparisons between multiple sites and landscapes in order to address questions about landscape use, cultural transmission, and broad questions relating to the large scale patterns of human mobility and interaction. Intra-site spatial analysis compares material within individual sites in order to answer questions regarding spatial patterning and site formation.

Intra-site spatial analysis (henceforth, simply 'spatial analysis') relies on accurate data collected from the archaeological material. Spatial analysis is an effective tool for identifying various site formation processes and spatial patterns at archaeological sites and is central to the testing of site formation hypotheses in this dissertation. Early spatial works on the archaeological record incorporated methods from plant ecologists that examined clustering on plan maps (Marks, 1971; Dacey, 1973; Whallon, 1973, 1974; Washburn, 1974). As technology improved, many manuscripts and edited volumes

introduced studies that began to apply these techniques to various assemblages, in turn expanding the utility of spatial analysis in archaeological contexts, which is also reflected in the literature solely on the subject (e.g. Hodder and Orton, 1976; Clarke, 1977; Heitala, 1984; Blankholm, 1991; Kroll and Price, 1991; Conolly and Lake, 2006).

Over the last decade, a plethora of studies incorporating spatial analysis have contributed many different ways to understand and interpret spatial archeological data. Many studies use the spatial data simply for visualization purposes (Bunn et al., 1980; Kroll and Isaac, 1984; Andouze and Enloe, 1997; D'Andrea et al., 2002; Spikins et al., 2002; Nigro et al., 2003; Villa et al., 2010; Domínguez-Rodrigo et al., 2010; Izuho et al., 2009), while others use spatial distributions as a major part of their analysis and produce spatial statistics that supplement observations and interpretations (Kintigh and Ammerman, 1982; Hivernel and Hodder, 1984; Riguad and Simek, 1991; Moyes, 2002; Galotti and Piperno, 2004; Witt, 2005; Craig et al., 2006; Marin-Arroyo et al., 2009; Alperson-Afil et al., 2011; Galotti et al. 2011; Hill et al., 2011; Discamps et al., 2012; Galotti et al., 2012; Gabucio et al., 2013; Oron and Goren-Inbar, 2014). Such spatial analyses can reveal patterns of human behavior that are otherwise invisible to the archaeologists, such as using burned flint microartifacts at Gesher Benot Ya'aqov to understand where hearths were located despite not having found any preserved charcoal (Alperson-Afil et al., 2011).

As spatial analyses become more prevalent in archaeology, more importance is placed on establishing a primary context for archaeological and paleontological assemblages. Abiotic site formation processes can redistribute and transport material to secondary and tertiary contexts, but some of the aforementioned biotic traces may still be

present on the faunal material. Thus, an increased importance is placed on fabric analyses to compare archaeological deposits to modern analogues of formation processes. Fabric analysis examines the layout of stones and faunal material to determine if there are patterns in the direction of orientation and dip. If patterns occur, perhaps they can be explained by processes that are known to preferentially orient bones and stones. The goal of these analyses in the context of this dissertation is to examine two main questions: Are the stones and faunal material in their primary depositional context? If not, to what extent have these materials been moved by physical agents such as gravity and water?

Currently, many different fabric analyses have been conducted on slope deposits, which includes rockfalls, snow avalanches, debris flows, runoff, solifluction, and mudslides (Bertran and Texier, 1995; Bertran et al., 1997; Lenoble and Bertran, 2004; Lenoble et al., 2008; Bertran et al., 2010), and fluvial deposits (Isaac, 1967; Bar-Yosef and Tchernov, 1972; Dibble et al., 1997). Orientation of faunal material has also been examined in experimental and actualistic contexts including lacustrine deposits (Cobo-Sánchez et al., 2014), fluvial deposits (Domínguez-Rodrigo et al., 2014), and hyena den deposits (Domínguez-Rodrigo et al., 2012). In most cases, bone and stone orientations are consistent within deposit type in abiotic depositional environments. For instance, fluvial deposits generally result in preferred orientations with long axes of elongated specimens being either consistently parallel to the direction of flow, or perpendicular. Orientation is dependent on several factors including substrate and flow velocity (Domínguez-Rodrigo et al., 2014).

Biotic site formation processes, however, are most often random in their orientations, since hominins and carnivores are not consciously depositing material to

face similar directions. That does not mean, however, that they only produce assemblages without preferred orientation. Kerbis-Peterhans (1990) observed preferred orientation of bones near the entrance of a hyena den, where they followed the slope of the entrance, which was subsequently found to be statistically significant by Domínguez-Rodrigo et al. (2012). Unfortunately, studies of bone orientation in carnivore dens are rare.

Many ethological works do indeed advance the understanding of how carnivores interact and use their living spaces, with a heavy focus on hyenas (e.g. Kruuk, 1972; Mills, 1990). Several studies examine the territory use of hyenas (inter-site, e.g. Boydston et al., 2003; Boydston et al., 2006; Kolowski and Holekamp, 2008), but surprisingly few studies look at organizational patterns of hyenas within their dens (e.g. Kerbis-Peterhans and Horwitz, 1992; Pokines and Kerbis-Peterhans, 2007). The amount of literature asking the same intra-site spatial questions using other apex predators, including felids and canids, is similarly small (e.g. Smith, 1978; de Ruiter and Berger, 2000). Some studies on fossil hyena dens employ spatial analysis techniques and can be helpful for comparative purposes, though these are only interpreted as hyena assemblages and may not have been solely created by hyenas (e.g. Villa et al., 2010). The paucity of analogous actualistic or modern assemblages in the present limits the comparative nature of the archaeological and paleontological material. Some experimental studies attempt to model how carnivores scatter bones, but these are in highly controlled and confined environments and have focused on carnivore ravaging of experimentally created assemblages rather than their bone deposition behavior (Marean and Bertino, 1994; Camaros et al., 2013). In order to circumvent this issue at present, inferences of carnivore space use rely heavily on the patterning of like taphonomic characteristics of bone, such as carnivore gnaw marks.

Conversely, bone accumulation behavior by humans is well studied in the present as well as the past. Ethnoarchaeological studies are essential for tying together behaviors that lead to material deposition and the resulting deposits. These analogues, however, have their limitations in how far they can project into the human past, since modern human behavior is a recent phenomenon and primarily attributed to our species. Therefore, it is essential to simultaneously examine observations and interpretations from both ethnoarchaeological and archaeological research when moving beyond modern human contexts.

Ultimately, this dissertation uses this analytical foundation to examine abiotic and biotic site formation processes at Dmanisi, Georgia. Taphonomic analyses show that biotic agents modified much of the assemblage, but were they contributing to the accumulation of the stones and faunal material as well? Clear evidence of hominin spatial organization declines sharply as one moves back in time, and there are precious few glimpses into these patterns of organization in the Lower Paleolithic. The Dmanisi assemblage provides a unique opportunity to explore these biotic contributions to site formation while also examining abiotic contributions.

DISSERTATION STRUCTURE

This dissertation consists of three co-authored papers; two of which address site formation evidence directly and a third paper that provides an additional line of evidence to understand different ways a fragmented faunal assemblage reflects the biotic agent responsible for its deposition. Each paper is intended to be submitted to a peer reviewed

journal, which will be outlined in each paper description. Additionally, abridging chapters and a concluding chapter relate the papers and research to one another within the greater context of archaeological research. I also include a chapter that reviews the different ways in which humans and animals are understood to use their living spaces, and the behavioral theory surrounding the observations.

All three papers are exploring the archaeological and paleontological material within the context of the early *Homo* site of Dmanisi, Georgia, although the third paper addresses this indirectly. The assemblages from the Block 2 and M6 excavations at Dmanisi, the foci of the papers, retain excellent three-dimensional provenience data, allowing for an accurate assessment of the spatial relationships used in conjunction with taphonomic interpretations by Martha Tappen and geologic and archaeological interpretations by Reid Ferring.. Block 2 is characterized by phases of pipe and gully fill above and below horizontal ashfalls, which lay upon a complex basalt formation that depresses in the northeast, acting as a major control for deposition. M6 is a small test unit that uncovered a thick gully fill deposit that has a much thicker (~2 m) accumulation of stones and faunal material than in the B1 strata of Block 2.

The Dmanisi assemblage consists of a diverse group of fauna, including an array of fossils from five individuals of early *Homo*, stone tools of the Oldowan character, and close spatial associations between these two types of material. The faunal sample described thus far (Tappen et al., 2007; Lordkipanidze et al., 2007) indicates some degree of carnivore and hominin involvement. The degree of carnivore and hominin contributions to the accumulation of the assemblage is still being investigated, but carnivore modified bones are far more prevalent than hominin modified bones (Tappen et

al., 2011, 2013). The subject discussed in the third paper sets the stage for advanced analysis of bone breakage to understand the extent of carnivore-hominin interaction that may not be observable from surface modifications alone. All three papers will be valuable contributions to the ongoing study of the Dmanisi archaeological and paleontological material and the context surrounding the earliest members of our genus to exit Africa.

Paper 1 is a co-authored paper where I am the lead author followed in order by Reid Ferring, Martha Tappen, Maia Bukhsianidze, and David Lordkipanidze, and it addresses abiotic site formation processes at Dmanisi, Georgia, by investigating several lines of evidence. This paper is titled "Spatial analysis and abiotic formation processes in Block 2 and M6 at Dmanisi, Georgia," and has yet to be submitted for publication, but the intention is to submit it to the *Journal of Human Evolution*.

Previous studies of Dmanisi have hypothesized that the initial bone accumulations in the B1 layers of Block 2 were primarily deposited by biotic agents including carnivores and hominins rather than resulting from fluvial deposition or reworking (Vekua et al., 2002; Lordkipanidze et al., 2007; Tappen et al., 2007), but some slumpage into gullies and lows spots possibly occurred (Tappen et al., 2007). M6 is thought to be gully fill deposits (Ferring, 2014.). Tests for preferred orientation, post-depositional movement, and winnowing examine the degree of autochthony of these assemblages, and enable comparisons to other site formation processes at other sites (e.g. Benito-Calvo and de la Torre, 2011; de la Torre and Benito-Calvo, 2013; Domínguez-Rodrigo et al., 2012, 2014). Anatomical refits and associated bones are also used as evidence for the extent of each depositional layer.

The results of these tests demonstrate that the deposition of stones and faunal material in each stratigraphic layer is reliant on the topography of the underlying stratum on which the archaeological and paleontological material accumulated. B1 and B1z, though at the same elevation, are not related strata. Depsite this, they both sit above B1x, which is above B1y. The basalt topography constrains the deposits in the lower elevations (B1y and B1x) to the northwestern portion of Block 2. B1y represents either remnants of pipe fill or the first phase of gully fill, while B1x sits above B1y and is gully fill. B1y is near the basalt and is relatively flat, with no preferred orientation, whereas B1x slopes to the south-southeast at its higher elevation and then flattens out as the deposits spread to the east. The basalt here is a major control for the accumulation of stones and faunal material in these layers, and it is less of a factor in B1, B2, and B3. B1z is also gully fill and the archaeological and paleontological material within is constrained by the walls of the gully, which display sharp erosional contacts with B1 and B1x.

The anatomical refits and associated skeletal elements, which primarily consist of hominin post-cranial bones described by Lordkipanidze et al. (2007), indicate very close associations between the skeletal material in each stratum. Bones attributed to the Skull 5 individual (D4500/2600) and the edentulous individual (D3444/3900) are found within B1y and those attributed to the young adult individual (D2700/2735) are found within B1x.

In order to test for winnowing, we analyze fragmentation, where we would expect there to be a dearth of smaller stones and faunal material if differential transport occurred. Though only general sizes (i.e. cobbles and pebbles) are used for the stones, an

abundance of faunal material of all sizes indicates that no depositional or post-depositional processes differentially deleted skeletal material based on size.

Based on these lines of evidence, we posit that Dmanisi is not a result of long-distance or high-velocity transport and much of the archaeological and paleontological material is in or very near to its original depositional context. By establishing this context, the spatial patterning of the stones and faunal material becomes ever important for examining biotic site formation processes, which are discussed in the following paper.

Paper 2 examines the spatial distribution of stones and faunal material in order to locate patterns that could be indicative of biotic agents of bone accumulation, such as hominins, carnivores, or rodents. The paper is not yet submitted, but is co-authored where I am the lead author followed by Reid Ferring, Martha Tappen, Maia Bukhsianidze, Medea Nioradze, and David Lordkipanidze and entitled "Spatial patterning of the archaeological assemblage at Dmanisi, Georgia: An analysis of site formation and carnivore-hominin interaction in Block 2", with the intention of submitting to the *Journal of Human Evolution*.

Building off the previous paper and previous hypotheses, this paper aims to answer questions about agent-specific biotic site formation processes by using spatial patterning. In order to effectively analyze the contribution to the assemblage by various bone collecting mammals, we stratify the spatial data based on different zooarchaeological and taphonomic variables. Various spatial analyses are employed, including kernel density estimates and chi-squared tests, which are supplemented by distribution maps. The data are analyzed on a layer by layer basis for the B1 sub-strata,

since they are the hominin bearing strata and where the densest accumulations of bones are located. Other strata contain too little taphonomic data (such as in Block 1) or are too highly affected by Medieval storage pits to perform an effective analysis. Subsets of the overall distribution are analyzed by comparing their distribution with their parent distribution, i.e. the distribution of carnivore bones should follow the overall distribution of faunal material if they were deposited randomly. If the subset does not follow the overall distribution, and the chi-squared test resulted in a significant difference, the null hypothesis is rejected and perhaps behavioral processes contributed to the differential distribution.

Overall, nearly all of the subsets of stones and faunal material follow the distribution of their parent material. Only the chi-squared test on the distribution of coprolites resulted in a statistically significant difference. Though this is the only aberration in the spatial patterning, the implications for behavioral processes are huge. Studies on extant carnivores, namely hyenas, show that hyenas differentially use space by defecating in certain areas: in latrines outside the den and sometimes in a designated area within a den (Hughes, 1958; Skinner et al., 1980; Skinner and van Aarde, 1981; Brain, 1981; Kerbis-Peterhans and Horwitz, 1992; Berger et al., 2009). The basalt formation in Block 2, with a vertical slab separating the north and south areas, could have provided a secluded enclosure for carnivores to consume a carcass in one area and defecate in another.

The coprolite distribution, along with the higher totals of carnivores in B1y and B1x, provides additional evidence in support of this being a predation hot spot (Tappen et al., 2007). Evidence for denning is certainly present, but multiple carnivore species and

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hominins, to a lesser degree, likely contributed to the large accumulation of bone in Block 2.

Paper 3 examines the efficacy of using bone fracture angles to determine the breakage agent of a fragmented assemblage. This paper is co-authored with Martha Tappen and Katrina Yezzi-Woodley and is entitled "New analytical methodology for comparing bone fracture angles: A controlled study of hammerstone and hyena (*Crocuta crocuta*) long bone breakage." This paper was reviewed by two anonymous reviewers, accepted for publication in *Archaeometry* pending revisions, and will be re-submitted before June 12.

Previous studies have reported that measuring fracture angles on bone fragments is a useful gauge of how the bone was broken, though with varying results (Alcantara-Garcia et al., 2006; de Juana and Domínguez-Rodrigo, 2012). We suggest that the fracture angles are likely affected more by differences in long bone shape and cortical bone thickness than the agent of breakage. In order to test this hypothesis, we compare fracture angles measured with a goniometer from various subsets of hammerstone broken bones to each other in order to understand the relationships between the different types of break orientations and limb bone elements. We test the potential for inter- and intra-observer error in order to ensure replicability. Finally, we present preliminary comparisons between the assemblages broken by hammerstone and by hyena to determine if the two agents create assemblages that are distinguishable based on their fracture angle distributions.

Our findings show that there are no statistical differences in goniometer measurements between observers' measurements and within a single observer's measurements. We also ran several tests between different variables of our assemblage to ensure that some other factors were not affecting our results, which included tests between fracture angles on adult and juvenile specimens, frozen and fresh bones, break planes with lengths between 2-4 cm and those greater than 4 cm, and two different marrow acquisition strategies that we used. In each case, these variables were not significantly different.

In addition to these tests, we tested for differences between skeletal elements and limb portions, the latter of which are upper (femora and humeri), middle (tibiae and radii), and lower (metapodia). These tests resulted in the most interesting results, as bone morphology seems to play a major role in how the fractures propagate throughout the bone. Due to these results, we suggest that when comparing fracture angles, archaeologists should compare like elements to one another, or at least to limb portion, i.e. upper, middle, and lower limb bones.

Our comparison between hammerstone and hyena broken bone did produce statistically significant results on the sample consisting of elk femora. These results are considered preliminary and we are currently expanding the sample to include more elements.

This paper offers a new statistical approach to comparing fracture angle assemblages and contributes a large experimental sample to the body of knowledge on bone breakage. The analytical approach that archeologists currently use for comparing

fracture angles should consider these results, in addition to some of the biases that we observed while collecting data. The goal of analyzing fracture angles is to establish a methodology in which we can utilize large portions of an archaeological assemblage that otherwise would not be included to assess the biotic site formation processes. When fragmented bones lack traces of the agent that broke them, fracture angles are a potentially valuable line of evidence from which we can extract information. For this reason, it is paramount that we understand the fracture dynamics of marrow rich bones.

Paper 1:

Spatial analysis and abiotic formation processes in Block 2 and M6 at Dmanisi, Georgia

SUMMARY

Previous interpretations of site formation at the Early *Homo* site in Dmanisi, Georgia, reconstruct a scenario of rapid burial with little to no post-depositional movement. These interpretations are based on taphonomic and geologic observations (Lordkipanidze et al., 2006, 2007; Tappen et al., 2007). This paper contributes an alternative method to test these interpretations and the depositional context of the stones and faunal material in Block 2 and M6 at Dmanisi.

This study examines orientation and dip, fragmentation and winnowing, and skeletal refits in order to examine the degree in which post-depositional movement affected the assemblage, with a primary focus on the B1 strata. The B1 deposits are divided into sub-strata (B1, B1z, B1x, and B1y) and are the strata in which all hominin skeletal material has been uncovered to date.

Each line of evidence supports the previous interpretations that the faunal material was not deposited by fluvial or colluvial action, but rather carnivores played a major role in the accumulation of bones in the B1 strata. Some evidence of colluvial deposition is apparent in B2. Complex erosional pipes and gullies created unique formations in which carnivores could have used for dens or protection from a highly competitive carnivore guild. Likewise, lithic artifacts were deposited by hominins, but their contribution to accumulating the faunal assemblage is likely small. This study presents evidence used at

Dmanisi for the first time to understand the depositional context and set the stage for a more in depth analysis of spatial patterning.

1-INTRODUCTION

   Interpretations of site formation processes at Dmanisi, Georgia, reconstruct the accumulation of faunal material by biotic agents (i.e. carnivores and hominins) and possibly some natural deaths, showing little evidence of fluvial deposition or long distance transport (Gabunia et al., 2000; Vekua et al., 2002; Lordkipanidze et al., 2006; Lordkipanidze et al., 2007; Tappen et al., 2007; Ferring et al., 2011). Currently, these interpretations are based on geological and taphonomic observations and analyses. This paper contributes further evidence that supports these interpretations, including orientation and dip, anatomical refits and associated bones, and an examination of fragmentation, the first of such evidence reported from Dmanisi.

   Understanding the depositional history of a site is integral for establishing the integrity of the archaeological context. Fabric analysis, or "the study of the orientation and dip of the artefacts" (Lenoble and Bertran, 2004: p. 457), is one effective method for understanding depositional processes and estimating the contribution of these processes to archaeological deposits. First employed in archaeology by Glynn Isaac (1967), fabric analysis has been widely used by Paleolithic archaeologists as a tool for understanding burial processes and site formation (e.g. Bar-Yosef and Tchernov, 1972; Schick, 1986; Kaufalu, 1987). More recently, comprehensive analyses at other sites have laid the groundwork for effective interpretations of fabrics and abiotic site formation processes (e.g. Bertran and Texier, 1995; Kluskens, 1995; Bertran et al., 1997; Lenoble and

Bertran, 2004; McPherron, 2005; Dibble et al., 2006; Benito-Calvo et al., 2009; Bernatchez, 2010). By working with the established methodology for fabric analysis, we can better compare interpretations between sites and assess contextual integrity for impending spatial analyses.

In this study, we use three methods for analyzing fabrics at Dmanisi: Visualization with rose diagrams and stereonet plots, statistical tests for preferred orientation, and analyzing orientation and dip simultaneously using eigenvalues and Benn diagrams. These analyses function under the idea that there are four primary fabrics, as outlined by Lenoble and Bertran (2004: p. 458): "(i) the artefacts are disorganized (isotropic fabric), (ii) they are lying flat on the stratification plane (planar fabric), (iii) they have a preferred orientation along a particular direction, usually the slope (linear fabric), and (iv) they are imbricated, i.e. they are overlapping." In other words, isotropic fabrics have no preferred dip or orientation, planar fabrics have a preferred dip but not orientation, and linear fabrics have a preferred dip and orientation. Imbrication is similar to a linear fabric in the sense that it has preferred dip and sometimes preferred orientation, but the material is overlapping like a row of fallen dominoes or shingles on a roof (Boggs, 2006). Direction of flow can often be inferred from the orientation and dip of imbricated deposits. For this study, we will only evaluate the first three fabric types, as imbrication of the stones is not present in Block 2 or M6 (Lordkipanidze et al., 2006, 2007).

Several studies (Bertran and Texier, 1995; Bertran et al., 1997; Lenoble and Bertran, 2004) have established that different abiotic processes can lead to preferred orientations of stones, especially in alluvial and fluvial depositions. In addition, trampling

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can have significant effects on the original orientation and dip of both stones and faunal material. In an experimental trampling study using cattle, Fiorillo (1989) observed that bones can lose their preferred orientation after trampling on hard substrate, leading to planar fabrics. Alternatively, on softer substrates, trampling can create preferred orientation, especially on slopes, or it can create isotropic fabrics, as material becomes pressed into the ground at different angles (Gifford-Gonzalez et al., 1985; Lenoble and Bertran, 2004). If trampling were responsible for the bone orientations, we would expect trampling marks to be present on many of the bones.

Initial accumulations of stones and faunal material by biotic agents, such as hominins, carnivores, and large rodents, are created without intentionally orienting material in certain directions (Bernatchez, 2010). Thus, we would expect that assemblages created by biotic agents to usually lack preferred orientations.

Used in tandem with fabric analyses, evidence of winnowing can support hypotheses regarding the transport and eventual deposition of stones and faunal material. In different fluvial environments, size classes of sediment, rocks, and bones can be differentially transported due to size and transport potential (Behrensmeyer, 1988). Some extensive experiments have examined the transport potential of bones (Voorhies, 1969; Boaz and Behrensmeyer, 1976; Coard and Dennel, 1995; Coard, 1999), and conclude that articulated and disarticulated specimens can have different transport potentials. At Dmanisi, there are many articulated specimens that have been found *in situ*, including nearly entire vertebral columns with articulated ribs, and these articulations and associated skeletal elements can supplement the analyses of transport potential. By using these different analyses for both stones and faunal material, we demonstrate that fluvial

deposition and long distance, high-velocity transport are not responsible for the

archaeological accumulation in Block 2 and M6 at Dmanisi, and accumulation by biotic

agents (i.e. carnivores and/or hominins) is the most parsimonious explanation.

1.1 *Background*

Dmanisi is a Paleolithic site located in the Kvemo Kartli region of southern

Georgia (Figure 1.1a). Situated on a promontory at the confluence of the Masavera and

Pinezauri rivers, excavations of the fossil-bearing strata began in the early 1980s and

have been systematically excavated at various locations across the promontory since. The

first hominin bone was discovered in 1991 in Block 1, where the first two crania were

also found, and subsequent hominin skeletal material has been found in other excavation

areas. Most of the hominin bones are from Block 2, which, along with M6, will be the

primary focus of this paper, due to the data collection methods and expanded excavation

area (Figure 1.1b).

Block 2 was first excavated by a Georgian-German collaboration starting in 1992

and lasting until 1999, with the northernmost reaches of the excavation ending at the 60N

line. Subsequently, in 2000, a Georgian-American collaboration began excavating north

of 60N and this collaboration and excavation continues today. Much of the data used here

are from the Georgian-American excavations, including all excavated archaeological and

paleontological material from the pipe/gully fill sub-strata of B1: B1x, B1y, and B1z.

With this caveat in mind, henceforth Block 2 shall refer to all material from both periods

of excavation, since the taphonomic and stone data span the entire excavation unit.

A complex stratigraphic sequence in Block 2 (Figure 1.2) is explained by a series of erosional pipes and gullies (Lordkipanidze et al., 2006; Lordkipanidze et al., 2007; Tappen et al., 2007; Ferring, 2014). The base of the depositions is ~70m thick basalt, which has a unique depression that likely dictated much of the site formation processes. The sediments are divided into two main strata: A and B. The A strata, A1-A4, are subsequent ash falls and are of normal polarity (Gabunia et al., 2000; Lordkipanidze et al., 2006, 2007). After the deposition of A4, B1 formed as another ash fall, though of reverse polarity, which characterizes all of the B sediments. Once B1 formed, pseudokarstic erosional pipes began to form within the A sediment, which then eventually breached and the surface then collapsed, allowing for the formation of gullies (Ferring et al., 2011; Ferring, 2014, 2015; See Bull and Kirkby (1997) for discussion of gully processes). The sediments that filled these pipes and gullies are separated into different sub-strata of B1 sediments: B1y, B1x, and B1z. Each B1 sub-stratum has a different spatial distribution, with B1y and B1x being primarily contained within the basalt depression (Figure 1.3b and 1.3c). B1y is either a remnant of the initial pipe fill or is the first stage of gully fill after the collapse of the pipe (previously assigned to B1p by Jöris, 2008). B1x and B1z are gully fill. There are firm erosional contacts between B1x and B1z and B1z and B1, the latter pairing being at a similar elevation. A2-A4 serve as walls and the roof to B1y and the walls of B1x in various locations of Block 2. The overlying B strata, B2-B4, are subsequent ash falls that are relatively horizontal. (Ferring, 2014, 2015)

Because of this complex B1 stratigraphic sequence and the significance of the hominin and megafaunal remains within, we address several questions in order to test the

original taphonomic and geologic interpretations. Taphonomic analyses demonstrated that majority of the bones in the B1 strata show little to no weathering, indicating limited exposure to sub-aerial weathering conditions, few bones show evidence of rounding due to transport, and only a "handful" of specimens show "evidence of abrasion indicative of trampling or geologic transport" (Tappen et al., 2007, p.126). Furthermore, the sediments themselves are not fluvial and there is high degree of whole and/or identifiable bones that show relatively little breakage, which also indicates little to no post-depositional movement (Tappen et al., 2007). Ultimately, the stones and faunal material in the B1 strata appear to be in or very near their primary depositional context.

With the stratigraphic sequence and these previous hypotheses in mind, we address the following questions. Are there different fabrics depending on the stratum? If so, can these differences be explained by the spatial constraints presented by the underlying topography of the basalt? Are anatomical refits and associated bones present and do they span different elevations/layers? Is there evidence of winnowing or differential transport of either stones or faunal material? Ultimately, this paper supplements previous interpretations by using new evidence to test abiotic site formation hypotheses and by demonstrating that much of the stones and faunal material in Block 2 and M6 at Dmanisi are in or very near their original depositional context.

2-METHODS

This paper focuses on the stratigraphic layers in Block 2 and M6 at Dmanisi. Block 1 lacks the data that is necessary to perform such analyses. Although ~125m^2 of

Block 1 was excavated, most of this was of stratum B2 and above, and only 9m^2 were excavated in and below the pedogenic calcareous layer, or "kerki", below which all hominin skeletal material to date have been recovered. Nearly all of the excavation in Block 2, however, has reached the underlying Masavera basalt, which allows for an analysis of quite a large area (~100m^2). Since 2002, all stones and faunal material larger than 2 cm were plotted using a total station (Trimble), though smaller identifiable bones and artifacts were also usually plotted. Points for each elongated *in situ* specimen were taken at the center and at each end. The two end points were then used to calculate orientation and dip angles, based on published methodology for Microsoft Excel (McPherron, 2005). Rose diagrams and stereonet plots were generated using Stereonet 8 (Allmendinger et al., 2013; Cardozo and Allmendinger, 2013). The bins of the rose diagram indicate the direction of the dip.

In addition to Block 2 data, stones and faunal material from a 7m^2 excavation unit, M6, are examined (Figure 1.4). M6 was opened by the Georgian-American team in 2000 as a test pit and excavations ceased in 2007, with only five of the seven 1m^2 squares having been excavated to the basalt. Nearly all of M6 is in a massive B1 layer and appears to be gully fill, though the full extent of the gully was not located in the excavation unit. Likely due to the ~2 m thick deposit, the density of faunal material per square in M6 is much greater than what is seen in the pipe/gully fill sub-strata of B1 in Block 2 (Material density per m^2: M6=280 , B1x=51 , B1y=48, B1z=57). In addition, the bone sizes in M6 are much smaller and more fragmented than in Block 2, which likely plays a larger role in the higher bone density estimations. The M6 gully is quite different

than what is seen in Block 2, but the particularities of this gully have not yet been fully defined (Ferring, pers. comm.).

Due to ambiguity concerning how to measure orientation on irregularly shaped bones (e.g. scapulae, innominates, vertebrae), only long bone and rib elements are used for the orientation and dip analysis. The analysis includes all rib and long bone shaft fragments larger than 3 cm. In order to compare orientations for different layers, three statistical tests for uniformity were applied based on current orientation studies (e.g. de la Torre and Benito-Calvo, 2013; Domínguez-Rodrigo et al., 2014): the Rayleigh, Watson, and Kuiper tests. The former tests uniform distributions against unimodal distributions and the latter two test for any deviation from a uniform distribution. The null hypothesis for each test is a uniform distribution, as we would expect that the random deposition of all material would result in orientations distributed in all directions. Probability values less than 0.05 are considered statistically significant and indicate non-uniform distributions. Although sample sizes are preferred to be larger than 40 for these circular statistics (see Lenoble and Bertran, 2004, for discussion), meaningful results can still be generated from the few that have smaller sample sizes here. Statistics were run using the 'circular' package in R (v. 3.0.2).

To consider orientation and dip simultaneously, eigenvalues (S1, S2, and S3) are generated based on clustering around three mutually orthogonal eigenvectors, the first of which is parallel to the axis of maximum clustering within the data (Watson, 1966; Benn, 1994; McPherron, 2005; Bernatchez, 2010). The arrangement of the data is explained by three main organizations: 1) If the eigenvalue for the first vector is high and the other two are low, then the data are linear, or are arranged in the same direction; 2) if the first two

eigenvalues are equal, then the data are planar with no preferred orientation, but all have similar dip values; and 3) if all three eigenvalues are close to equal, the data are isotropic: there is no preferred direction of orientation or dip (Benn, 1994; McPherron, 2005). Eigenvalues were calculated for each available stratigraphic layer using Stereonet 8 (Allmendinger et al., 2013; Cardozo and Allmendinger, 2013).

In order to visualize their relationships to one another and how they represent different types of orientation patterns, Benn diagrams are used and indicate the type of fabric we would expect based on the Isotropy Index ($I=S3/S1$) and the Elongation Index ($E=1-(S2/S1)$) (Benn, 1994). The three main organizations described in the previous paragraph plot on the Benn diagram in different ways: 1) If there is a high S1 and low S2 and S3, I is low and E is high, resulting in a placement near the linear corner, 2)if S1 and S2 are close to equal, but higher than S3, E and I are both low and represent planar fabrics, and 3) if all eigenvalues are equal, then E will be low and I will be high, indicating an isotropic fabric. In essence, isotropic fabrics have no preferred orientation or dip, planar fabrics have a preferred dip but not orientation, and linear fabrics have both preferred orientations and dip.

In addition to orientation and dip, we analyze the presence and spatial distribution of three groups of conjoining bones: associated elements, articulating bones, and anatomical refits. We refer to associated elements as non-articulating bones attributed to the same individual, articulating bones as those that are found in articulation, and anatomical refits as elements from to the same individual that articulate but were not found in articulation. Anatomical refits and articulating bones are represented by several different taxa, but the associated bones consist primarily of bones attributed to three

hominin individuals (Lordkipanidze et al. 2007, 2013). These data only include obvious anatomical refits, as a systematic attempt at refitting bone fragments has not yet been undertaken (e.g. Morin et al., 2005; Rosell et al., 2012), nor has a similar process been completed for lithic artifacts (e.g. Villa, 1982). Many individuals of the same species are located in the same area, also making anatomical refits difficult to determine unless they are found in direct articulation. Despite this, we present a sample of associated, articulating, and refit elements from the Dmanisi assemblage.

Winnowing and density mediated attrition can bias the assemblage towards certain bone dimensions and certain skeletal elements, respectively. Piece plotted bones are quantified and analyzed to assess the degree of winnowing. In order to examine density mediated attrition due to transport, bones are placed in groups depending on their transport potential, based on Voorhies (1969). Group 1, bones that are removed immediately by saltation or flotation, consists of ribs, vertebrae, sacra, and sternum. Group 2, bones removed gradually by traction, consists of all long bones as well as the pelvis and sometimes the ramus (whether ramus includes the horizontal and the vertical ramus is not specified). Long bone shaft fragments unidentifiable to skeletal element or taxa are not included. Some bones, e.g. scapulae, ulnae, and phalanges, could be part of groups 1 or 2 and are treated as a separate group. Group 3, those bones that lag behind, consists of crania and mandibles, which can include the ramus. These groupings are very simplistic and do not fully encompass all of the variables that can affect bone transport, including how transport affects fragmentary specimens, but they do allow for a basic assessment of transport.

Since the experiment by Voorhies (1969) used coyote and sheep bones, we limit our analysis to include only elements from similar sized mammals (~size class 1 and 2). Coard and Dennel (1995) and Coard (1999) ran experiments with both articulated and disarticulated skeletal elements from similarly sized animals and observed that transport potential increased on some articulated elements; their results are considered during our analysis and interpretations, along with results from flume experiments using human bones (Boaz and Behrensmeyer, 1976), guanaco bones (Kauffman et al., 2011), and fragmentary long bones (Pante and Blumenschine, 2010). We include whole and mostly whole bones, where mostly whole bones are those that are nearly complete, but are missing a very small portion, usually on processes. Consequently, the transport potential of mostly whole bones is considered the same as whole bones in this study.

Preliminary data for screened and collection-bag material are also presented. Screened material refers to stones and faunal material recovered during the screening and wet sieving processes and collection-bag material are those that are found during excavation but fall below the 2 cm cut off for mapping with the total station. The screened and collection material are grouped by square and elevation, the latter of which is typically in ~10cm intervals. Faunal material is quantified by size into 1 cm bins (e.g. 0-1 cm, 1-2 cm, etc.), and stones are split into sizes of greater than or less than 1.8 cm. The sample includes data from B1 in M6 and B1z and B1 in Block 2, and only bone fragments that exhibit non-excavation breaks are reported. Though sampling bias is present in the current sample, we are still able to make some inferences based on what we have so far.

3-RESULTS

3.1. *Orientation and Dip*

The orientation of the long bones in the strata of M6 and Block 2 shows a generally anisotropic pattern, with the exception the bones in B1x of Block 2, which returned statistically significant results in each test for uniformity (Table 1.1). No divisions of the stone sample show statistically significant preferred orientations, though sample sizes are much lower in the B1 strata compared to the faunal sample. Some orientations appear to be in preferred directions (e.g. B1z), which could be real patterns but not significant simply because of the small sample sizes. In any case, general observations of directionality can be discussed.

The B1 sample primarily includes B1a, which is a relatively flat layer interpreted as an *in situ* ash fall (Lordkipanidze et al., 2006, 2007; Ferring et al., 2011) with a gentle west to east slope, and possibly small portions of the B1x, B1y, and B1z strata, but post-excavation reassignments using stratigraphic profiles have yet to be completed. The B1 rose diagram shows no preferred orientation (Figure 1.5a). However, the Elongation and Isotropy indices for B1 (Table 1.2) for both stones and faunal material plot more towards the linear fabric on the Benn diagram (Figure 1.6). The linear fabric of the stones is likely a result of the small sample size (*n*=15), but could represent the actual pattern.

The B1z sediments are thinly bedded gully fill that overlie B1x, and are inset against B1. The B1z sample size is relatively low, but does have a slope southward, which is apparent from its low Isotropy index (Table 1.2) and stereonet plot (Figure1.5b).

B1x was deposited in the remnants of a gully that formed above the B1y sediment. In the western area of the gully (63-65E and 62-63N), the B1x bones seem to follow the contours of the gully, which is sloping in a generally south-southeast direction and represents a primarily planar fabric. Additional orientation data are needed in other areas of B1x to fully understand this phase of deposition, but the general slope of the layer is expected to continue as it follows the direction of the gully.

The B1y sample includes bones from the context surrounding the adult (D4500/2600; Skull 5) and edentulous (D3444/3900) individuals, with the D4500 cranium located underneath the basalt overhang. In this area, the stones and faunal material are generally constrained by the western edge of the basalt, which slopes slightly in an eastern direction. The rose diagram and stereonet plot of the faunal material reflect this trend (Figure 1.5d), though the statistical tests for preferred orientation are not significant. Both stone and faunal material from B1y are plotted near each other and towards the planar corner on the Benn diagram.

All but one assemblage (B1y bones) have I values lower than 0.21 and all but assemblages (B3 bones and B1 bones and stones) have E values less than 0.4. B1 stones are located closest to the linear corner of the plot, while most others are closer to the planar plot (Figure 1.6). With the relatively higher I, B1y is more isotropic than all other layers, which indicates that the dip values are more varied than in the other layers. Low I values for other layers indicate that they all generally share a similar dip direction. This can be interpreted as each layer follows a similar plane, with some having slightly more preferred orientations, though not significantly so.

3.2. *Refits and associated bones*

Anatomical refits and associated bones are common in the B1 layers of Block 2, though much of the data have not been fully collected and processed. As a result, these data should be considered preliminary. The maximum distance between refits is 3.63 m and the mean is 0.82 m. As reported previously by Lordkipanidze et al. (2007, 2013), hominin elements attributed to individuals are spatially distinct, both horizontally and vertically (Figure 1.7).The skull 5 individual (D4500/D2600) and the edentulous individual (D3444/D3900) are firmly in B1y, and the sub-adult individual (D2700/D2735) is in B1x (Lordkipandize et al., 2007, 2013). Three bones from the sub-adult individual were found at higher elevations, one being a metatarsal that is in the upper B1x sediments, close to the contact of B1z. The other two elements are teeth that fit into the cranium and mandible and are also in the B1x sediments, but at higher elevations due to the steep slope of B1x north of 62N. The location of these is interesting in that it represents a close association between the B1z and B1x gully fill phases.

Though there are a large number of bones in a small area, M6 only has five sets either conjoining or anatomical refits, two of which are part of the same anatomical sequence (Figure 1.8). One refit spans 17 cm of elevation and the maximum distance between refits is 1.14 m, with an average of 0.48 m. An expanded study on anatomical refits should inform further on the relationship between faunal material in these excavation areas.

3.3 *Bone fragmentation and winnowing*

When looking at the Voorhies (1969) transport groups for whole and mostly whole bones of size class 1 and 2 mammals in the B1 layers, each group is represented (Table 1.3). Groups 1, 2, and those that can be in both groups have similar sample sizes. Group 3 is likely much lower due to the fragile nature of cranial and mandibular remains, as many near complete crania are present in these layers, but do not entirely fit the category "whole". The lower number of specimens in Group 3 is also lower compared to the other groups because each individual animal only has one head and mandible, as opposed to multiple long bones; forthcoming analysis of skeletal part frequencies should inform further on these observations. Stratigraphic layers at lower elevations have higher counts of bones eligible for categorization, but this is expected due to the denser distribution of bones in these layers (Figure 1.9). Many more of these elements are present, yet fragmented.

Table 1.4 shows that each of the size bins of whole, mostly whole, and fragmented bones in B1 strata are represented with relatively high sample sizes compared to other strata, with the exception of the largest bin (>32 cm). The presence of bone fragments in each smaller bin is important to note, since they would most likely be winnowed away during transport. Figure 1.10 shows the spatial distribution of these smaller size classes in order to highlight their abundance in the B1 strata. Interestingly, B1x has a higher percentage of whole bones (Table 1.4) compared to all other layers (30.25% versus 0-16.27%), and it is greater than expected based on the overall average of B1 bones (19.83%). M6, B2, and B3 exhibit a higher degree of fragmentation than in the B1 strata of Block 2.

Preliminary analysis of screened material and collection-bag data shows the presence of hundreds of bone fragments smaller than 2 cm in the western B1 sediment above the basalt (Figure 1.11a). The data are biased towards B1 strata at higher elevations and the less dense parts of Block 2 because not all collection bags have been processed yet, which does not allow us to use these data to fully address winnowing factors in B1x and B1y. Very few screened and collection-bag materials have been processed from B1x and B1y, and none are from elevations lower than 1015.3 m, which excludes the densest areas of accumulation. Nonetheless, we can show that many small bones in B1 and B1z are represented. At this point, these data are not complete enough to confidently analyze over the whole of Block 2.

Screened and collection-bag material from M6, however, are more evenly sampled and the largest representations are from squares 3 and 4 (Figure 1.11b). In total, 1012 bones smaller than 2 cm are located in M6 (Table 1.5). If we look only at where both stone and faunal material are represented (squares 3 and 4), 672 stones smaller than 1.8 cm are present, compared to 807 bones smaller than 2 cm, which suggests that the remainder of the squares would probably have comparable numbers of stones and faunal material. When added to piece-plotted specimens (1219 bones; 646 stones), screened and collection-bag material more than double the counts of excavated stones and faunal material.

DISCUSSION AND CONCLUSION

The taphonomy and geology reconstruct a scenario with rapid burial and little post-depositional movement, which is supported by the fragmentation, transport groups, and orientation and dip. The associated skeletal elements and anatomical refits demonstrate non-compacted, thick depositional layers of large mammal bones, which accumulated rapidly considering the observed lifespan of erosional pipes and gullies and low degrees of bone weathering (Tappen et al., 2007; Ferring, 2014). A hypothesis of low-energy, short-distance dispersal of faunal material followed by rapid burial (Lordkipanidze et al., 2007) is supported by the general dearth of evidence for the contrary: No winnowing, little density mediated attrition, or differential distributions of Voorhies (1969) transport groups. Forthcoming taphonomic analyses of each layer are expected to support these observations. In any case, the presence of all Voorhies groups, especially those that are transported away first when they are articulated or disarticulated, indicates that no differential transport seems to have acted upon the individual or articulated bones, as there are large quantities of both. Pante and Blumenschine (2010) experimentally tested transport potential for fragmented long bones on three different size classes of mammals and found that smaller bone sizes and bones from smaller size classes of mammal are more likely to be transported. As our fragmentation data show, bones from all size classes are present throughout the B1 sequence. Additionally, close spatial associations of specimens attributed to single individuals indicate little post-depositional dispersion.

The bone orientations show that the general distribution of bones in each layer is dependent on the paleoslope, which generally slopes to the east/south-east, but varies for

specific gully fill sub-strata (Ferring, 2014). B1x is the only stratum that resulted in a

statistically significant preferred orientation. The preferred orientation here is likely a

result of the morphology and slope of the erosional gully in which the stones and faunal

material were deposited, in addition to the size of the bones (mean length=17.5 cm,

max=75 cm). The northern portion of B1x (63-65E and 62-63N) is at a higher elevation

and shows clear dipping of the faunal material towards the south-southeast, where the

strata eventually flatten out due to the morphology of the underlying basalt. In a

comparable scenario, the distribution of faunal material following a slope has been

observed at a spotted hyena den in Maasai Mara, Kenya (Kerbis-Peterhans, 1990). Based

on these observations, deposition was not a result fluvial or colluvial transport.

Certainly, the pipes and gullies were formed by hydraulic processes, but the

subsequent deposition of stones and faunal material into these geologic formations was

not a result of fluvial or colluvial deposition. The mostly planar fabrics of each layer

support the idea that the distributions were reliant on the surface on which they were

deposited, i.e. there is no preferred orientation and the dips are generally in line with the

slope of the underlying surface: B2 was deposited on top of a relatively flat B1, B1 was

deposited on relatively flat A4, and the pipe and gully fills follow the general topography

of the pipes/gullies in which they were deposited. The two most linear assemblages are

both B1, but neither returned a statistically significant result in any of the tests for

preferred orientation, and both have relatively small sample sizes.

The fabric analysis at Dmanisi is based on the same methodology as used at other

Paleolithic sites, but many of the sites are not directly comparable to the depositional

processes we see in Block 2 and M6. The difference is primarily driven by the fact that

no fluvial sediments are found within either excavation location (Lordkipanidze et al., 2006, 2007; Ferring, 2014). Most analogues at present have been established for slope deposits, which includes rockfalls, snow avalanches, debris flows, runoff, solifluction, and mudslides (Bertran and Texier, 1995; Bertran et al., 1997; Lenoble and Bertran, 2004; Lenoble et al., 2008; Bertran et al., 2010), lacustrine deposits (Cobo-Sánchez et al., 2014), and fluvial deposits (Isaac, 1967; Bar-Yosef and Tchernov, 1972; Dibble et al., 1997).

In nearly all of their case studies on debris flows and solifluction, Bertran and Texier (1995) observed that the majority of stones in these course-textured slope deposits have their long axis oriented parallel to the slope. Similarly, Bertran et al. (1997) report similar observations from an expanded study of slope deposits. Both of these studies support the idea that the direction of the slope and the underlying structures are an important control for deposition. Lenoble and Bertran (2004) examine fabrics from 49 different layers of undisturbed and disturbed sediments and the resulting Benn diagram exhibits some overlap in the distribution of both the undisturbed and disturbed sediments, which introduces a degree of equifinality. Further studies on solifluction (Lenoble et al., 2008; Bertran et al., 2010) discuss extreme instances of post-depositional disturbance by solifluction and the spatial clusters and fabric organizations that can result, such as stones in formations described as sorted stripes and polygons that could look anthropogenic in archaeological contexts.

Cobo-Sánchez et al. (2014) examine natural wildebeest drowning in Lake Masek, Tanzania, and their subsequent deposition on shore. Of their five observation areas, four

show anisotropic orientations, indicating that even low energy water movement from the transgressive-regressive lake cycles and run-off can affect bone orientations.

Orientation studies on fluvially generated fabrics combine previous observations on bone transport (Voorhies, 1969; Boaz and Behrensmeyer, 1976; Coard and Dennel, 1995; Coard, 1999) with fabric analyses. More recently, orientations from Bed I at Olduvai Gorge, Tanzania, have been analyzed based on Mary Leakey's field maps (Benito-Calvo and de la Torre, 2011). Due to methodological disagreements of how to measure orientation from 2D excavation maps, Bed I has been considered at times to be a product of either fluvial deposits or hominin and carnivore activity (Benito-Calvo and de la Torre, 2011; Domínguez-Rodrigo et al., 2012; de la Torre and Benito-Calvo, 2013; Domínguez-Rodrigo et al., 2014). Domínguez-Rodrigo et al. (2012) incorporate multiple lines of evidence, including bone and stone refits, high counts of small bones and stones, and additional excavations, in order to argue that fluvial processes were not the agent responsible for the accumulation of faunal material in Bed I, and especially not at FLK Zinj.

Using multiple forms of evidence has resulted in a similar conclusion at Dmanisi. Nearly all of the assemblages plot with debris flows on the Benn diagram, but the composition of the assemblages at Dmanisi is completely different than what is found in debris flows. Many of the bones are found either in articulation or within close proximity with other bones from the same individual. Instances of rounding and abrasion are minimal and evidence for winnowing is not present. With none of these abiotic site formation processes evident at Dmanisi, the interpretation that the deposits of stones and

faunal material simply followed the underlying morphology of the landscape remains as the most parsimonious explanation.

Surely, sediment would have washed in over the archaeological and paleontological material deposited in these intermittent gullies after periods of precipitation, but the influence of these ephemeral water flows on transport and re-deposition was likely small and more akin to surface runoff, since the bones were not winnowed or re-oriented. When a new erosional gully formed in B1z, the force of flow was strong enough to develop clear erosional contacts, which are easily identifiable with B1 on its sides and B1x at its base (Figure 1.2; Ferring, 2014). The creation of B1z possibly led to some of the stones and faunal material at higher elevations in B1x being eroded and transported away, but did not impact the material located throughout the entirety of the layer. No clear erosional contacts between B1x and B1y indicate that, if gullies did form, the water flow within was not frequent enough, or strong enough, to transport away the existing stones and faunal material, but rather could have rapidly buried the material.

Based on these analyses, abiotic geologic processes likely had little contribution to the accumulation of the large densities of bone in the B1 strata. In contrast, much of the stones from B2 are located in the bottom of the layer (Figure 1.12), which is likely the result of bioturbation and colluvial transport (Ferring, pers. comm.). The B1 strata have stones spread both horizontally and vertically throughout. The higher densities of faunal material are located within the basalt depression in the northeastern half of Block 2, primarily in layers B1x and B1y (Figure 1.3; Coil et al., Paper 2). Within these layers, there is an abundance of carnivore bones, carnivore modified bones, and coprolites

(Tappen et al., 2007, 2011, 2013, 2015, in prep), which is strong evidence for bone accumulation by carnivores.

Tappen et al. (2007) described Dmanisi as possibly a predatory hot-spot, where carnivores (and hominins to a lesser degree) would predate upon large mammals at a high traffic water source. Certainly, the importance of this location arose from the abundance of water nearby, being a peninsula with a river on one side and a lake on the other, and the basalt and pipe/gully formations offered some seclusion for large carnivores to feed.

The abundance and diversity of large carnivores at Dmanisi, including members of Felidae (*Megantereon, Homotherium, Panthera, Lynx,* and *Acionyx*), Canidae (*Canis*), Hyaenidae (*Pachycrocuta*), and Ursidae (*Ursus*), along with interspecific predation and/or scavenging, suggests complex trophic dynamics among several apex predators. Consequently, the accumulation of much of the faunal material is considered to be a result of multiple carnivores, with little contribution by hominins. Hominins brought in a variety of types of lithic artifacts, including stone tools, flakes, and cores. With little evidence of post-depositional movement, the stones and faunal material in the B1 strata are likely very near the location of their original deposition. By establishing the integrity of Dmanisi's depositional context, forthcoming spatial analyses can inform on biotic depositional processes (Coil et al., Paper 2).
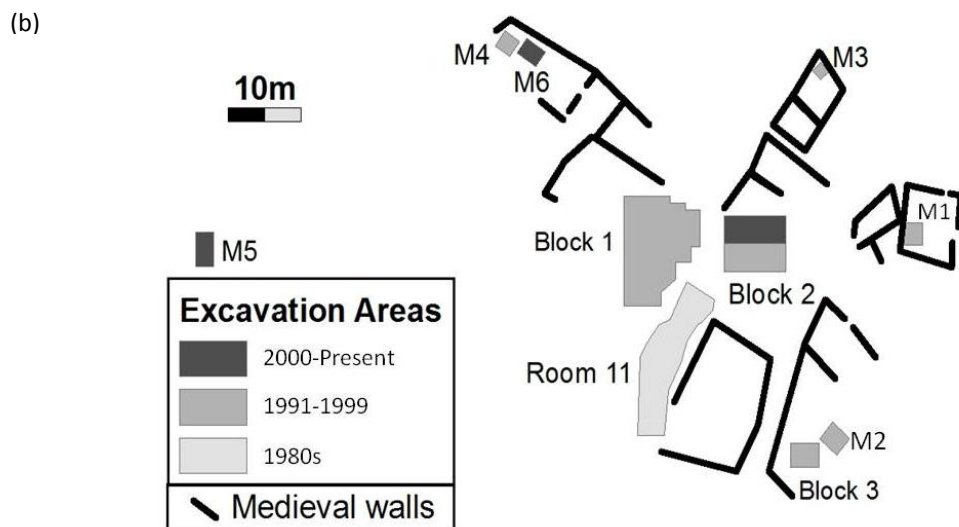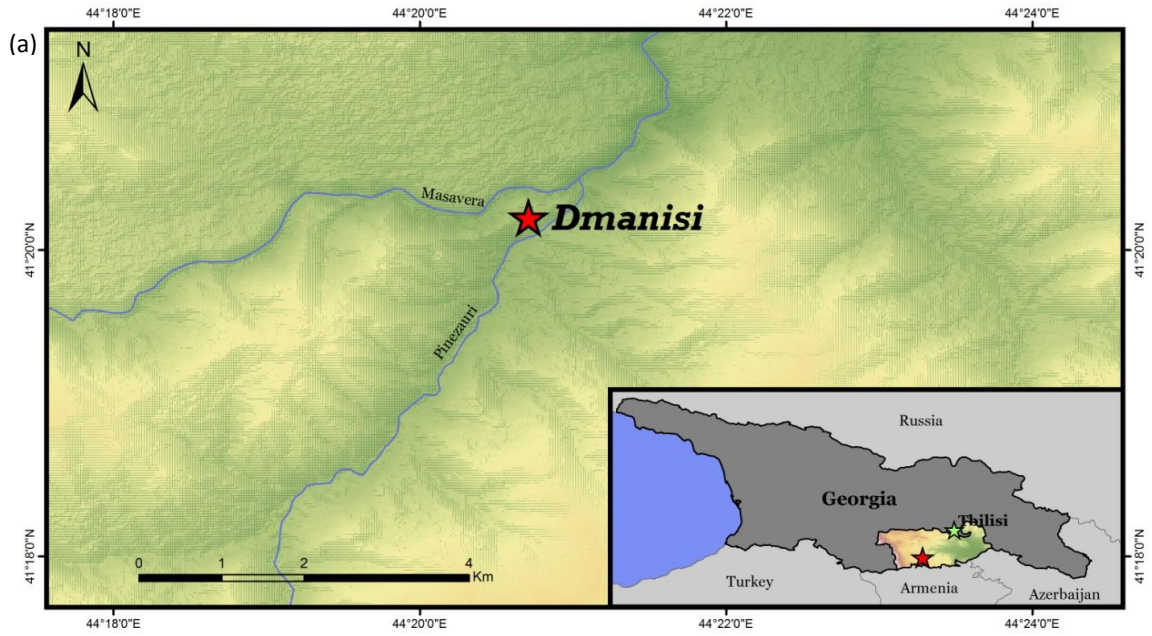
Figure 1.1: (a) Map of Georgia (inset) and location of Dmanisi. (b) Map of the excavation areas mentioned in the text (adapted from Ferring et al., 2011).
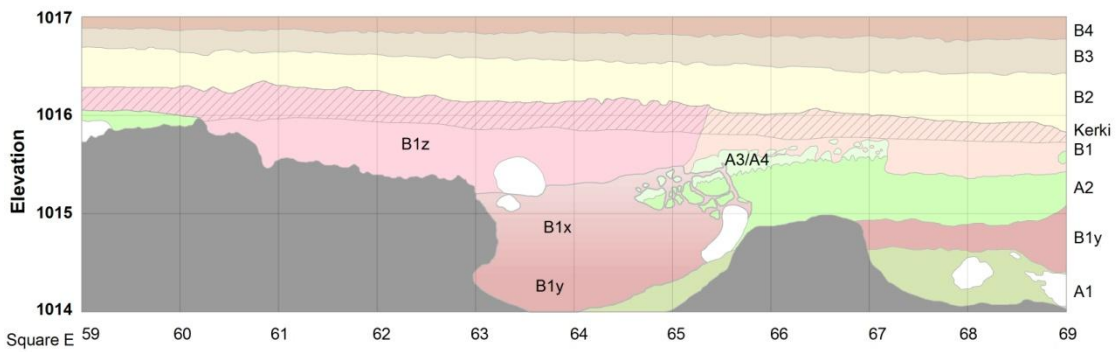
Figure 1.2. Stratigraphic East-West profile at 62N line in Block 2. Adapted from Ferring (unpublished data).
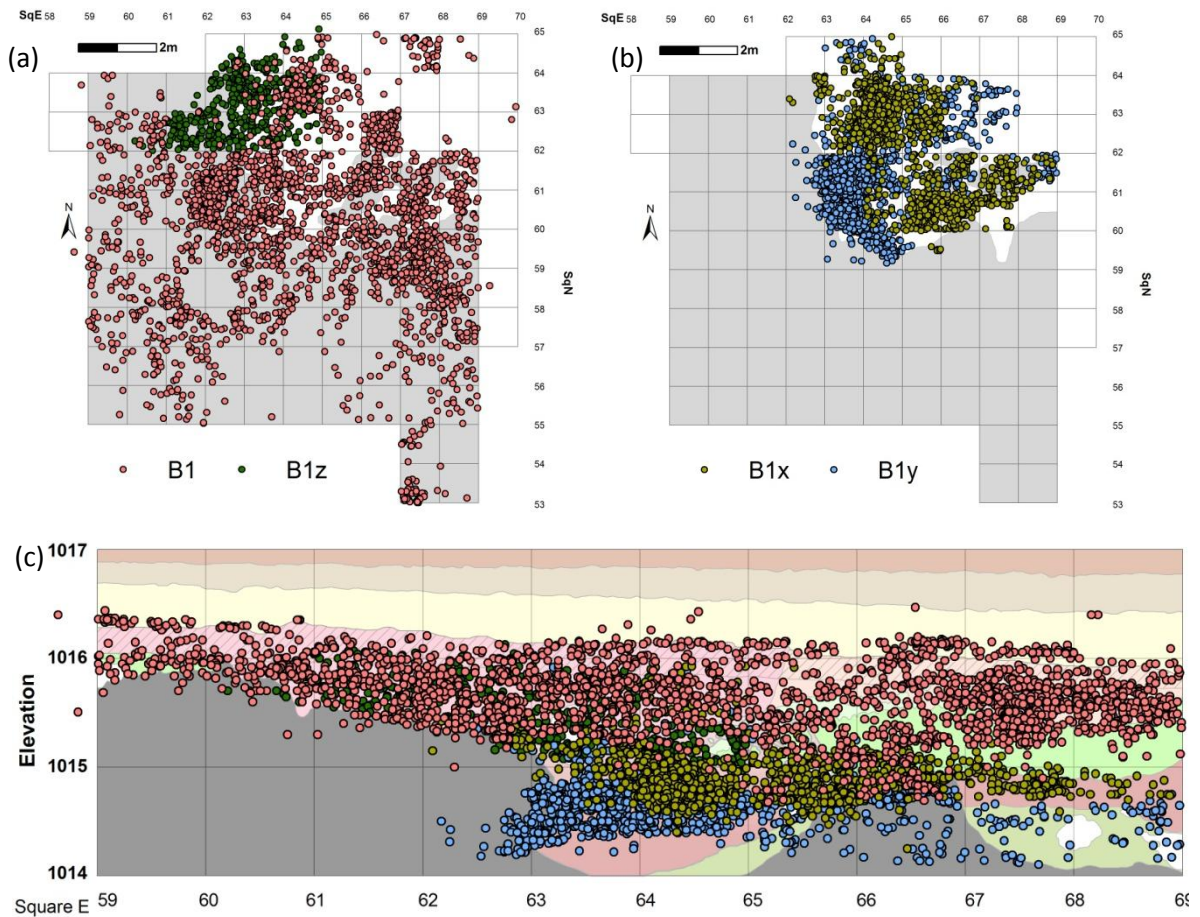
Figure 1.3. (a) Distribution of stones and faunal material from B1 and B1z, (b) distribution of stones and faunal material from B1x and B1y, and (c) East-West vertical profile of distribution of stones and faunal material all B1 strata. Refer to legends in (a) and (b) for the color codes of each layer. Note: due to high variability in pipe/gully fill deposits, where the points plot on the stratigraphic profile background is not an indicator of their actual stratigraphic assignment.
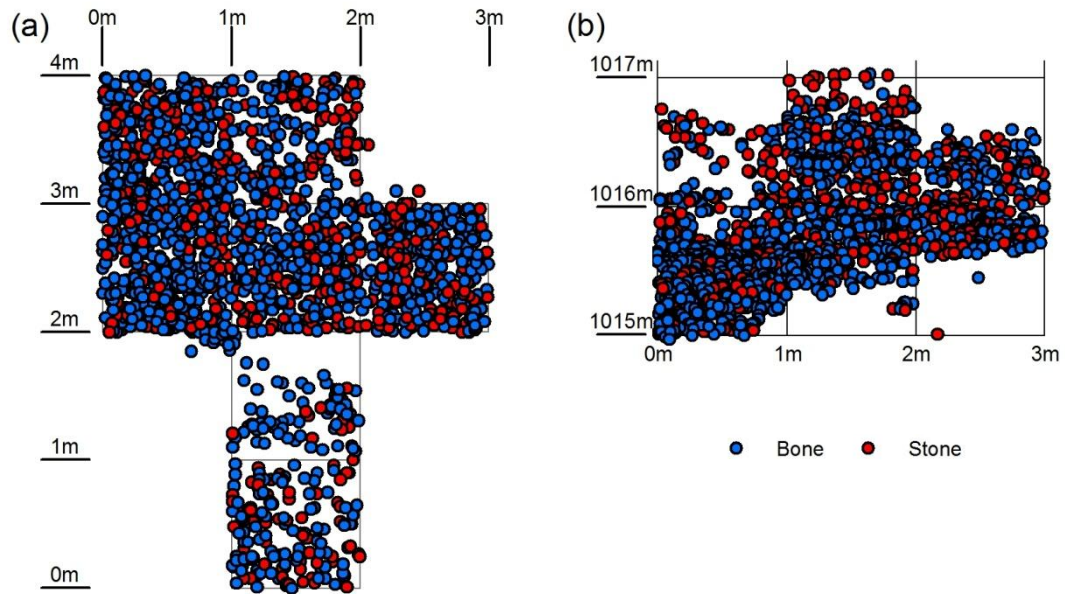
Figure 1.4: Distribution of M6 stones and faunal material in (a) plan and (b) East-West profile.

Table 1.1: Results of the Rayleigh, Kuiper, and Watson tests for the orientation data in Block 2 and M6. Bold typeface indicates statistically significant probabilities.

	Excavation Area	Stratum	*n*	Rayleigh (p)	Watson (p)	Kuiper (p)
Bones	Block 2	B3	20	0.617	>0.10	> 0.15
		B2	26	0.9102	>0.10	> 0.15
		B1	39	0.9709	>0.10	> 0.15
		B1z	27	0.8311	>0.10	> 0.15
		B1x	68	**0.017**	**0.01 < *p* < 0.025**	**0.01 < *p* < 0.025**
		B1y	102	0.0924	0.05< *p* < 0.10	0.05< *p* < 0.10
	M6	B1	25	0.1524	0.05< *p* < 0.10	0.05< *p* < 0.10
Stones	Block 2	B2	156	0.8383	>0.10	> 0.15
		B1	15	0.0663	0.05< *p* < 0.10	> 0.15
		B1y	13	0.9698	>0.10	> 0.15

(g)

(h)

(i)

(j)
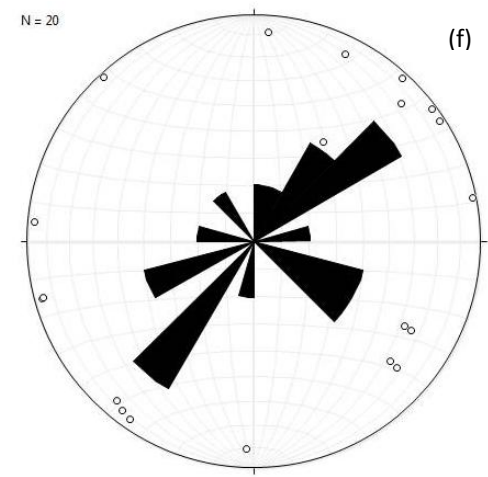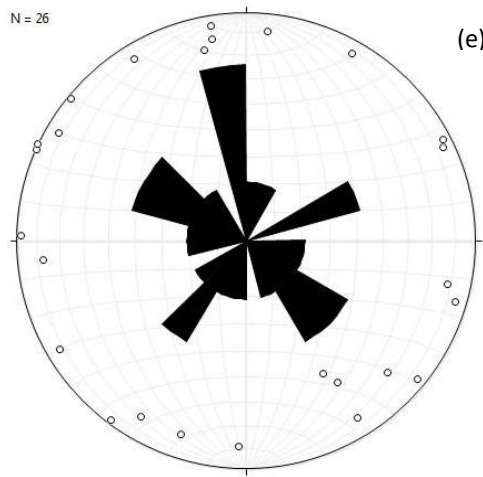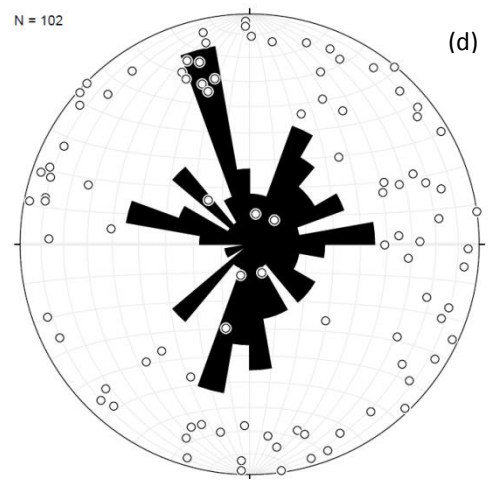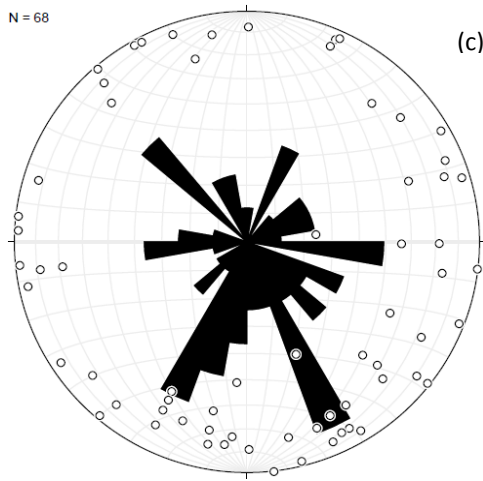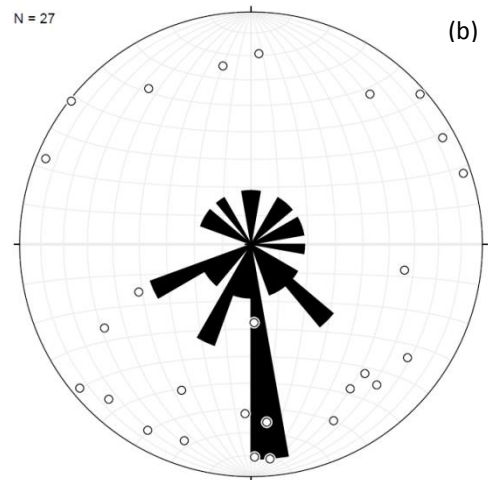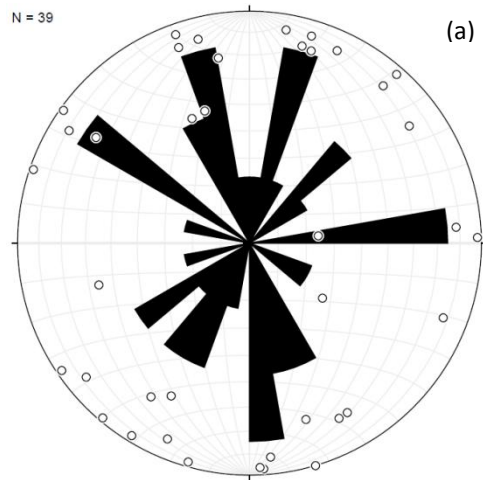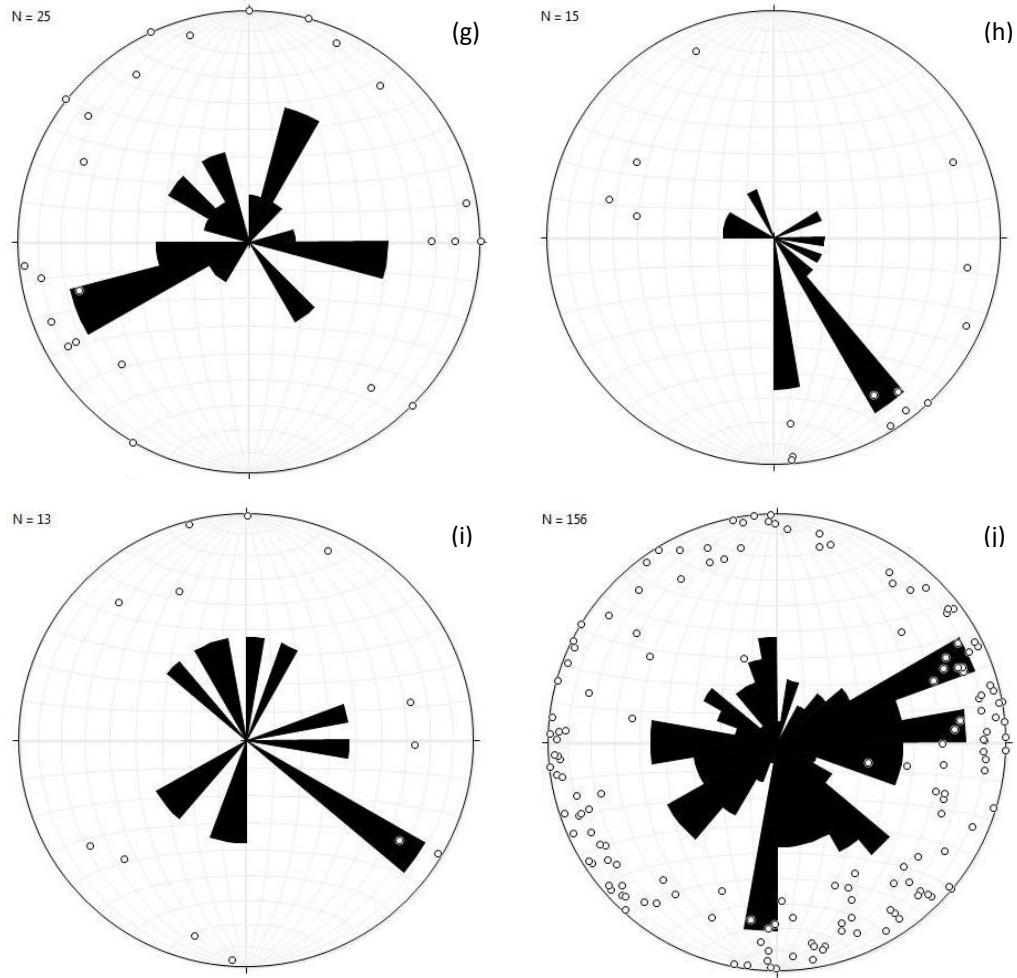
Figure 1.5. Rose diagrams and stereonet plots for bone orientation and dip data. (a) - B1, (b) - B1z, (c) - B1x, (d) - B1y, (e) - B2, (f) - B3, (g) - M6, (h) - B1 stones, (i) - B1y stones, and (j) - B2 stones
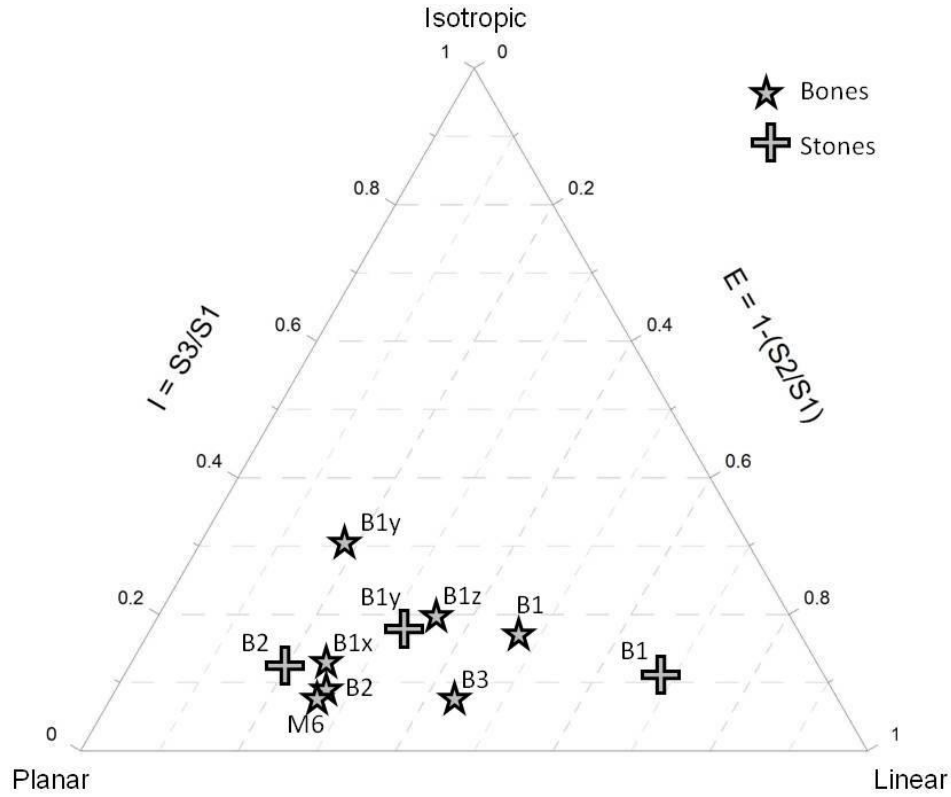
Figure 1.6. Benn diagram showing the placement of each B1 layer calculated using bone orientations (Star) or stone material orientations (plus sign). I= Isotropy index, E=Elongation Index.

Table 1.2: Sample sizes, Eigenvalues (S1, S2, and S3), Isotropy Index (I), and Elongation Index (E) for each layer separated by bone and stone material.

	Layer	n	E1	E2	E3	I	E
Bone	B1x	68	0.535	0.3965	0.0691	0.129159	0.258879
	B1y	102	0.4739	0.381	0.1451	0.306183	0.196033
	B1z	27	0.5438	0.343	0.1132	0.208165	0.369253
	B1	39	0.5867	0.308	0.1053	0.179478	0.47503
	B2	26	0.5628	0.3984	0.0388	0.068941	0.292111
	B3	20	0.6087	0.3423	0.049	0.080499	0.437654
	M6	25	0.5517	0.4022	0.0461	0.08356	0.270981
Stone	B1	15	0.6994	0.2189	0.0817	0.116814	0.687017
	B1y	13	0.5402	0.3652	0.0946	0.17512	0.323954
	B2	156	0.5213	0.4158	0.0629	0.12066	0.202379
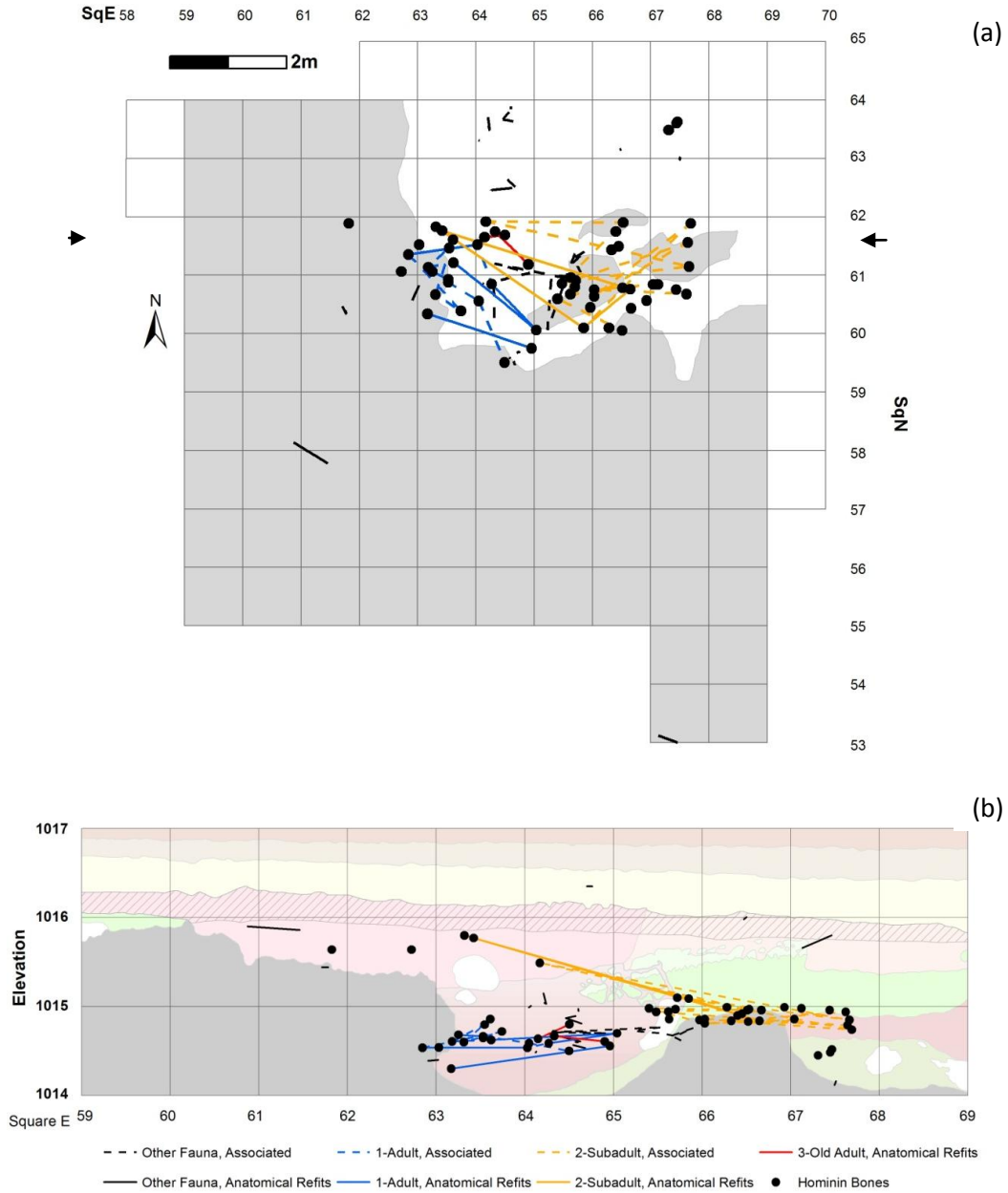
Figure 1.7. Anatomical refits and associated skeletal elements of hominin individuals and other fauna in B1 layers of Block 2 in plan (a) and East-West profile (b). One square = 1 m^2. The arrows in (a) indicate the location of the stratigraphic profile used as a backdrop in (b).). The thickness and architecture of the sediments vary over short distances both north and south of the 62N profile, so each bone shown in that profile is not necessarily within the strata on which it is displayed, since it could be as much as 9 m away.
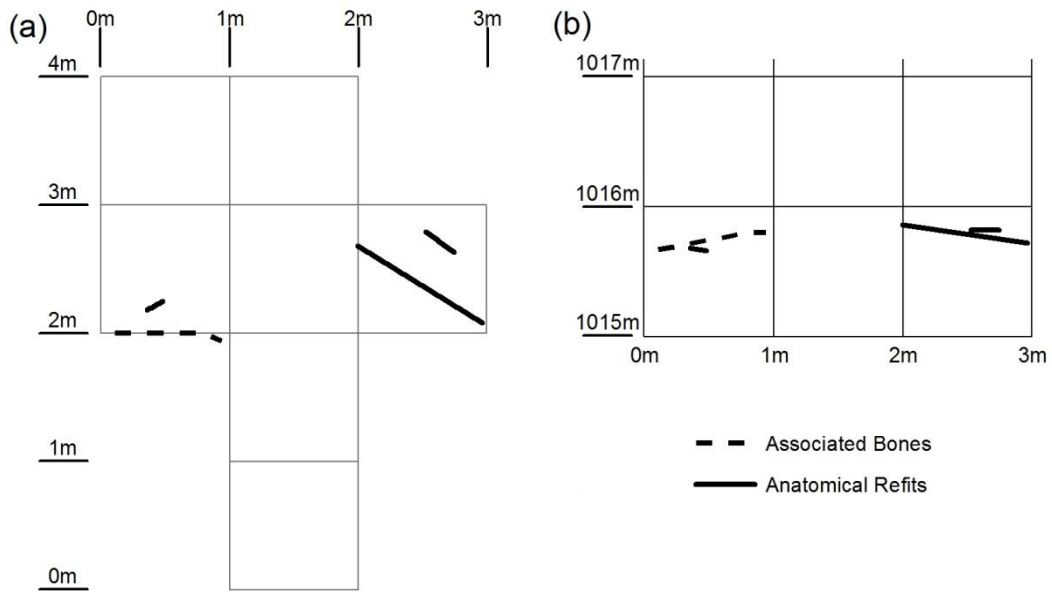
Figure 1.8. Anatomical refits and associated skeletal elements of fauna in M6 in plan (a) and East-West profile (b). One square = 1 m^2.

	Voorhies (1969) Transport Groups			
Completeness	1	1&2	2	3
Fragmented	62	41	179	81
Mostly Whole	29	3	9	0
Whole	16	42	54	3
Total	107	86	242	84

Table 1.3: Sample sizes of Voorhies (1969) transport groups for whole, mostly whole, and fragmented bones of size class 1-2 artiodactyls and carnivores in all B1 layers.
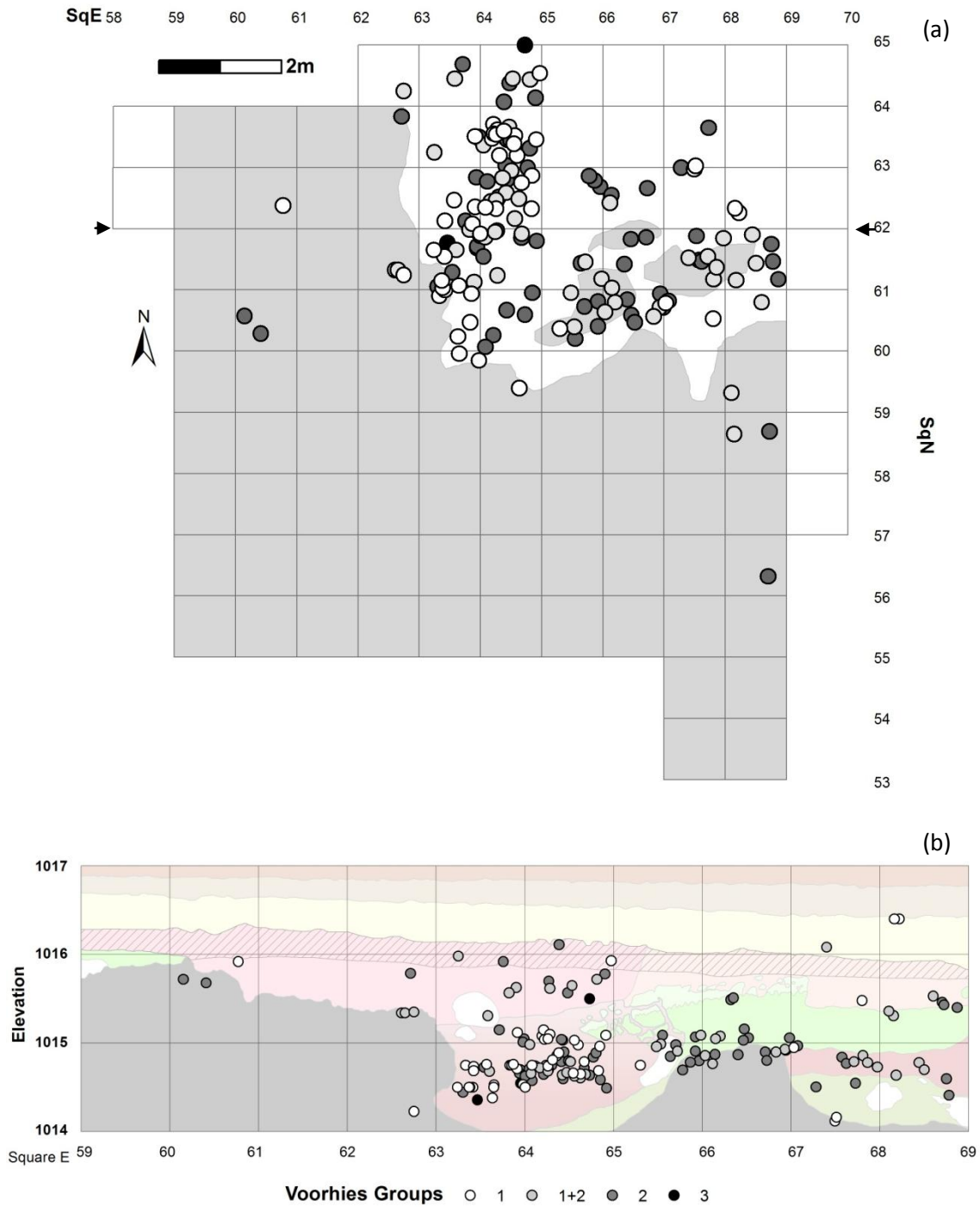
Figure 1.9. Voorhies (1969) bone transport groups for size class 1-2 carnivores and artiodactyls in B1 layers of Block 2 in plan (a) and East-West profile (b). One square = 1 m^2. The arrows in (a) indicate the location of the stratigraphic profile used as a backdrop in (b).
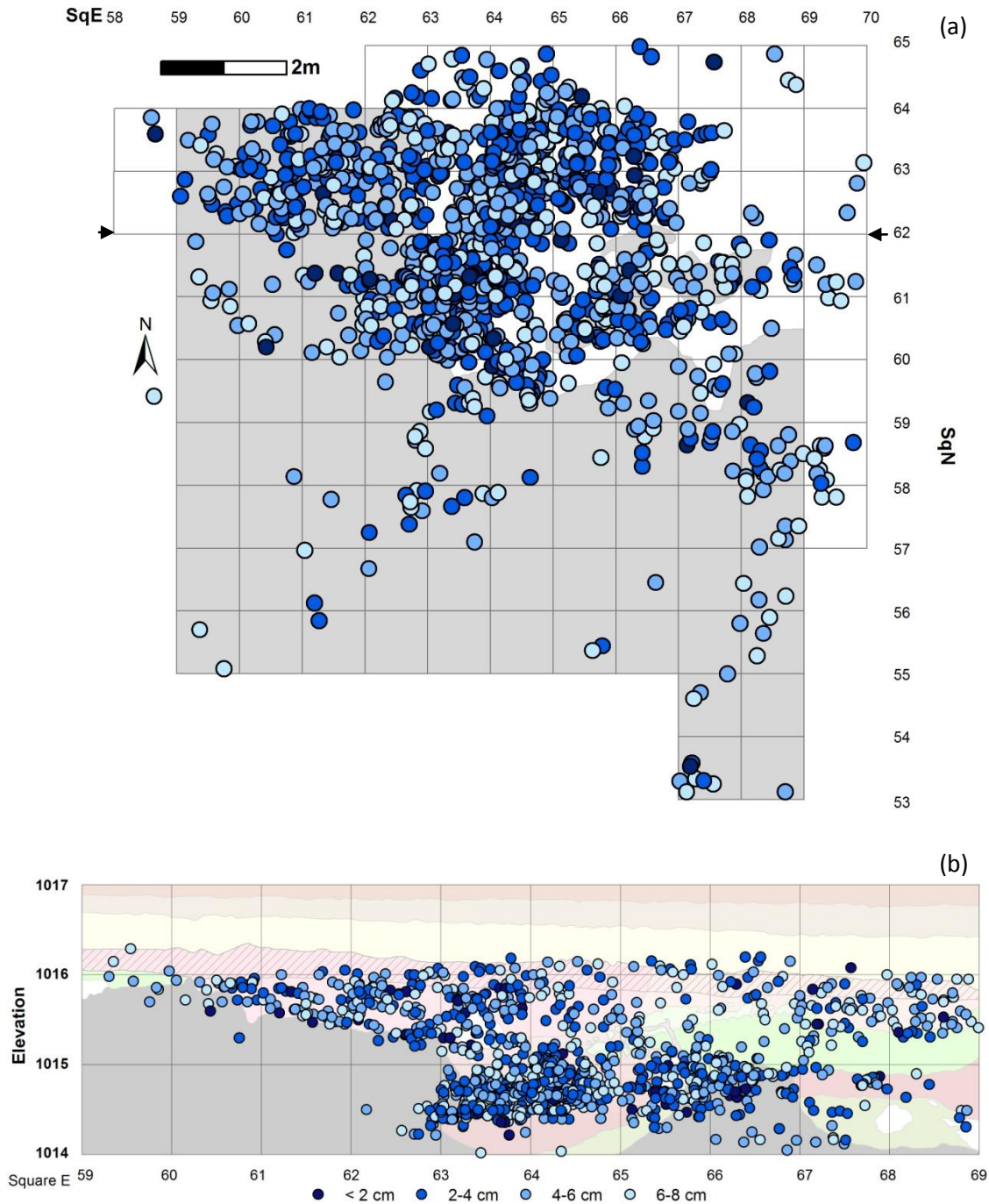
Figure 1.10. Distribution of faunal remains smaller than 8 cm in B1 layers of Block 2 in plan (a) and East-West profile (b). One square = 1 m². The arrows in (a) indicate the location of the stratigraphic profile used as a backdrop in (b).

Table 1.4: Counts and percentages of whole and fragmented bones with max dimension measurements.

Layer		All n	All %	<4 cm n	<4 cm %	4-8 cm n	4-8 cm %	8-16 cm n	8-16 cm %	16-32 cm n	16-32 cm %	>32 cm n	>32 cm %
B1	Whole	109	16.32%	29	27.36%	35	14.83%	13	6.88%	26	22.03%	4	23.53%
	Mostly Whole	26	3.89%	1	0.94%	6	2.54%	12	6.35%	4	3.39%	3	17.65%
	Fragmented	533	79.79%	76	71.70%	195	82.63%	164	86.77%	88	74.58%	10	58.82%
B1z	Whole	30	14.29%	15	28.85%	9	14.06%	3	4.55%	3	12.00%	0	0.00%
	Mostly Whole	23	10.95%	9	17.31%	7	10.94%	5	7.58%	1	4.00%	1	33.33%
	Fragmented	157	74.76%	28	53.85%	48	75.00%	58	87.88%	21	84.00%	2	66.67%
B1x	Whole	167	30.25%	66	60.55%	38	27.94%	14	9.40%	46	31.51%	3	25.00%
	Mostly Whole	59	10.69%	16	14.68%	15	11.03%	13	8.72%	10	6.85%	5	41.67%
	Fragmented	326	59.06%	27	24.77%	83	61.03%	122	81.88%	90	61.64%	4	33.33%
B1y	Whole	102	16.27%	45	32.37%	32	17.49%	9	4.59%	15	15.15%	1	10.00%
	Mostly Whole	48	7.66%	11	7.91%	16	8.74%	15	7.65%	5	5.05%	1	10.00%
	Fragmented	477	76.08%	83	59.71%	135	73.77%	172	87.76%	79	79.80%	8	80.00%
B1 All	Whole	408	19.83%	155	38.18%	114	18.42%	39	6.50%	90	23.20%	8	19.05%
	Mostly Whole	156	7.58%	37	9.11%	44	7.11%	45	7.50%	20	5.15%	10	23.81%
	Fragmented	1493	72.58%	214	52.71%	461	74.47%	516	86.00%	278	71.65%	24	57.14%
B2	Whole	15	5.60%	4	4.40%	8	6.96%	0	0.00%	3	14.29%	0	0.00%
	Mostly Whole	10	3.73%	3	3.30%	6	5.22%	1	2.50%	0	0.00%	0	0.00%
	Fragmented	243	90.67%	84	92.31%	101	87.83%	39	97.50%	18	85.71%	1	100.00%
B3	Whole	6	5.88%	0	0.00%	5	11.63%	0	0.00%	1	10.00%	0	0.00%
	Mostly Whole	4	3.92%	2	11.76%	2	4.65%	0	0.00%	0	0.00%	0	0.00%
	Fragmented	92	90.20%	15	88.24%	36	83.72%	32	100.00%	9	90.00%	0	0.00%
All A	Whole	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
	Mostly Whole	2	28.57%	1	100.00%	0	0.00%	1	16.67%	0	0.00%	0	0.00%
	Fragmented	5	71.43%	0	0.00%	0	0.00%	5	83.33%	0	0.00%	0	0.00%
M6	Whole	72	8.16%	38	10.05%	28	8.24%	3	2.24%	2	5.56%	1	50.00%
	Mostly Whole	16	1.81%	12	3.17%	4	1.18%	0	0.00%	0	0.00%	0	0.00%
	Fragmented	794	90.02%	328	86.77%	308	90.59%	131	97.76%	34	94.44%	1	50.00%
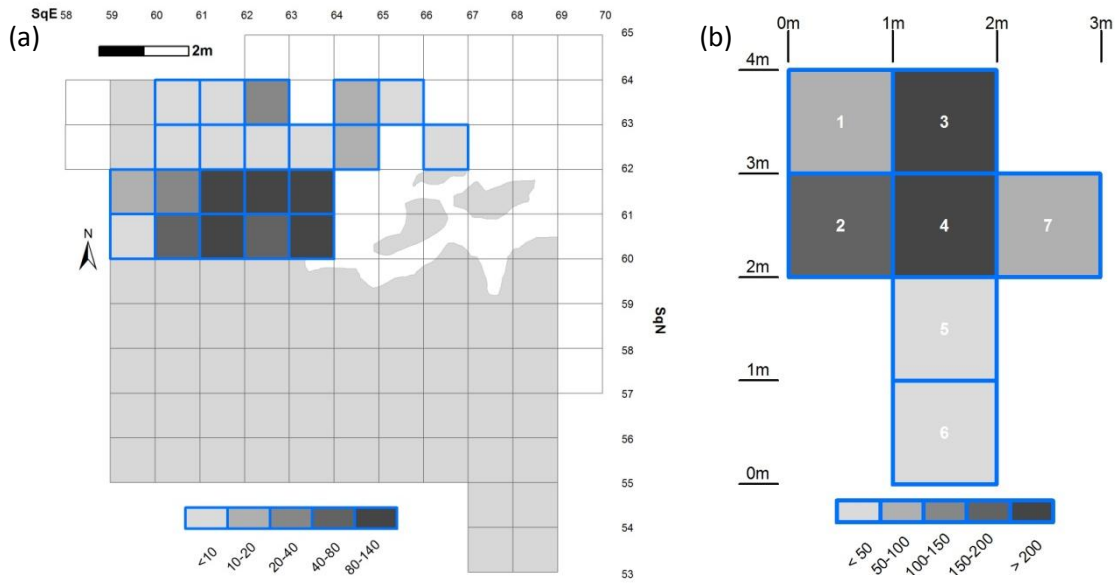
Figure 1.11: Sample of screened and collection bag material from (a) Block 2 and (b) M6. Different colors represent counts of screened and collection bag material.

Table 1.5: Collection bag and screened material from M6.								
	Bone						Stones	
Square	**0-1 cm**	**1-2 cm**	**2-3 cm**	**3-4 cm**	**4-5 cm**	**5-6 cm**	**<1.8 cm**	**>1.8 cm**
1	36	28	14	10	6	4	-	-
2	31	40	30	30	5	23	-	-
3	223	292	173	54	20	10	409	362
4	126	166	129	60	21	13	263	263
5	2	0	0	0	0	0	-	-
6	12	6	22	3	0	0	-	-
7	12	38	18	3	4	0	-	-
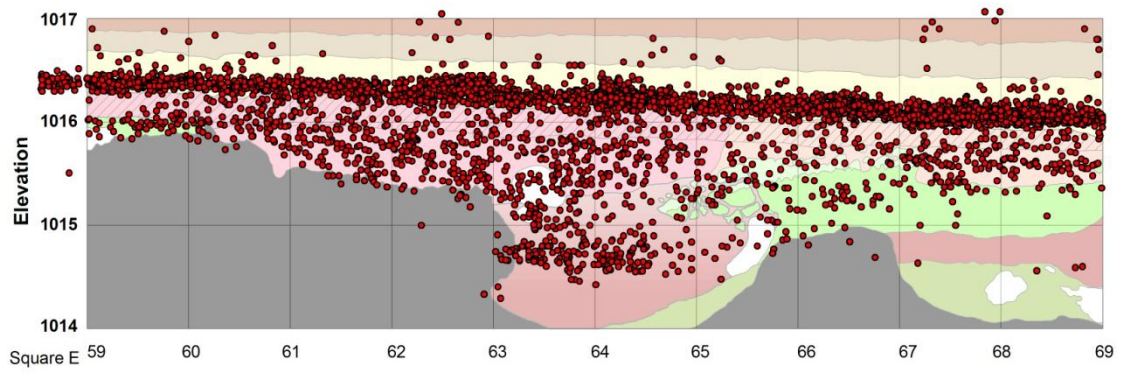
Figure 1.12. East-West profile of the distribution of stone material in all layers of Block 2. Note the dense accumulation of stone material at the bottom of B2.

ABRIDGING CHAPTER FOR PAPER 1 AND PAPER 2

The second paper builds off the results of the first paper, and needs to be considered in light of those results. The first paper uses different methods of fabric analysis to examine the contribution of abiotic site formation processes to the archaeological assemblage in Block 2 and M6 at Dmanisi. Previous hypotheses about site formation attribute much of the accumulation of faunal material to carnivore activity with little contribution by abiotic forces, such as colluvial and fluvial deposits. This paper tests these hypotheses using evidence analyzed for the first time at Dmanisi and is a necessary step for establishing the depositional context of the stones and faunal material.

By examining orientation and dip, winnowing, and articulating and associated bones, Paper 1 demonstrates that abiotic site formation processes had little impact on the accumulation of bone in the hominin-bearing strata, B1. Each layer exhibits a primarily planar fabric, where there is no preferred orientation but the dip values of each bone or stone are relatively similar. Representations from all size classes of stones and faunal material, both from screened and collection-bag material and piece-plotted material, are present in each of the hominin bearing strata, indicating no preferential deletion of either type of material based on size. Associated and articulating bones are frequent and are generally confined to within the substrata in which their respective pairs are located. This is mostly illustrated by the several hominin individuals located in the B1 strata, where each are confined to a specific sub-stratum. These results demonstrate that the stones and faunal material are in or very near to the location where they were originally deposited.

Paper 2 builds off of these results and examines the spatial patterning of the stones and faunal material. Spatial analyses are reliant on the understanding of site formation and the integrity of the depositional context. Since much of the stones and faunal material are near their original depositional location, performing a spatial analysis can inform on the relationships between different taphonomic subsets, which enable us to potentially locate behavioral processes. More specifically, we can assess if there are discrete depositional events that can be attributed to specific biotic agents, such as carnivores, rodents, or humans.

Paper 2 examines different subsets of the faunal and stone assemblages and their spatial relationships. By looking at different lines of taphonomic evidence, such as carnivore and hominin modified bones, it is possible to locate specific clusters of activity in different strata. We analyze the subsets of data compared to the entire distribution of stones and faunal material with the hypothesis that each subset should follow the same distribution as its parent material. If there are deviations from this overall pattern, then perhaps behavioral processes played a part in their accumulation.

Each co-author contributed different data and expertise to the paper. Reid Ferring shared his profiles and interpretations of the complex depositional sequence in Block 2 and M6. Martha Tappen allowed access to her taphonomic data. Both of these authors have been central to the interpretations of site formation that are tested and expanded upon in the following paper. Maia Bukhsianidze contributed to faunal identifications and taxonomic assignments, as well as clarifications on x, y, and z coordinates from the field notes held in the Georgian National Museum. David Lordkipanidze is the site director at

Dmanisi and in addition to finding all of the material, he allowed me access to the collections and excavation databases.

To preface the next paper, I have included a review of ethnoarchaeological and ethological studies on how humans and carnivores use their living space and accumulate stone and faunal material. This review serves as a foundation for which the spatial analysis builds upon, as we look to identify spatially discrete activities of different biotic agents. In order to do so, we must understand how material accumulates and what types of behaviors result in different types of deposits.

REVIEW CHAPTER:

Carnivore and Hominin Space Use and Material Accumulation

1-INTRODUCTION

Interpreting an archaeological site relies heavily on the analogues of processes that are apparent today. Dozens of factors can affect an archaeological/paleontological assemblage post-depositionally, including fluvial transportation, erosion, general decay, etc. Many of these factors are well studied and generally understood, but can vary highly in the outcomes. In addition to the variation seen in post-depositional processes, the initial deposition can vary highly as well. This chapter will examine the diversity of how carnivores and humans accumulate material, primarily bones for carnivore assemblages and a plethora of various materials for human-made assemblages, and attempt to sift through the high inter-assemblage variability in order to identify general trends seen in each accumulation agent and how these agents play a key role in site formation.

The important notions to understand when evaluating behavioral patterns of humans and carnivores are those revolving around life history and habitual behaviors. Though the life histories for each individual are highly variable, the life history of a species at the population level will be fairly predictable; in other words, animals will follow a typical timeline unique to their respective species. Hyenas, for instance, will eat meat and bones, and accumulate the latter at various places. Though the duration and size of these deposits will be highly variable, it is inevitable that every hyena will create a deposit, though not always in a concentration. Humans are also creatures of habit, though

those habits change depending on where and how individuals live. Although we live in a highly industrialized society, we accumulate refuse and waste the same as a forager in Africa or a horticulturalist in Australia; it is only how much material and how we deposit that material that varies. By understanding these behavioral patterns, archaeologists can begin to dissect assemblages in order to determine accumulating agents.

This chapter looks at various assemblages created by extant carnivores and human groups, primarily foragers, and examines how these actualistic and ethnoarchaeological data can be employed for interpretations at various archaeological/paleontological sites. The main questions that pertain to how this information can be translated into the past include: Do humans or carnivores habitually deposit material in a manner that is spatially recognizable? Would these patterns be observable in the archaeological record? How do these patterns affect site formation? The primary goal for this paper is to understand how humans and carnivores use space and if this space use can be identified in archaeological assemblages.

2-THEORY OF HUMAN SPACE USE BEHAVIOR

While there is a paucity of research on behavioral theory for understanding carnivore accumulations, there are several studies that address the interdependence of several factors on human created deposits. Susan Kent (1987) notes that humans are creatures of pattern with respect to three main factors: culture, cultural material, and behavior, and the relationship between the three. She suggests that these three factors affect the way that humans use space, and that, by understanding how people organize

and use space, the variables influencing this behavior, and the interrelationship with cultural material and aspects of culture, we can begin to develop theories to model and understand the past, present, and future use of space (Kent, 1987; see also Bartram et al., 1991, and Agorsah, 1988, for independent, yet similar, arguments). She thus states that the archaeological record is a result of patterning of behavior, culture, and cultural material.

Brooks and Yellen (1987) go a step further and describe how these relationships of activity overlapping in space contribute to a 'spatial redundancy.' They define 'spatial redundancy' as having five primary aspects: (1) Spatial redundancy is a key factor in the creation of large concentrations of debris, on the regional scale, (2) Reoccupation areas are more likely to enter the archaeological record, (3) Space and activities are conditioned by a combination of organizational and environmental factors, including the technology of hunting and transport, surface water availability, prey species behavior, and predator pressure, (4) Lookouts, ambush sites, and quarries are more likely to be spatially redundant than open air camps, since the former are more commonly associated with landscape features and special resource availability, and (5) Spatially redundant activities will be disproportionally represented in the archaeological record (Brooks and Yellen, 1987). They also point out that there are two types of sites that are used habitually: reuse, which refers to space being used repeatedly during the same occupation that intensifies the potential for archaeological identification; and reoccupation, which refers to space being used after an initial occupation that will most likely obscure the archaeological identification (Brooks and Yellen, 1987). The reoccupation sites are synonymous with palimpsests.

James O'Connell (1995) addresses concerns about the lack of a general theory of behavior in ethnoarchaeology, since ethnoarchaeology is effective in showing how archaeological behaviors create material deposits, but it does little to observe non-material behaviors that affect material behaviors, such as food-sharing and mating. In a roughly contemporaneous publication, however, Marshall (1994) finds differential patterns of bone accumulations in the Okiek of Kenya due to food sharing behaviors, which can replicate skeletal part frequencies related to archaeological signatures of differential transport. Though compelling evidence when skeletal material present, meat sharing does not always include the transfer of skeletal material. The latter scenario is where O'Connell's point is apt.

O'Connell also points out that sites are not routinely divided into activity specific areas, site structures are highly variable, and many variables affect how bones are removed from sites, and the fact that, at that time, current ethnoarchaeology acknowledges these issues, but does not actively address why they happen (O'Connell, 1995). In addition to these issues, he posits that site structure, and ethnoarchaeology in general, does not explain why people switch from foraging and collecting to hunting (See also O'Connell et al., 1991). Though never offering a solution besides a call for a comprehensive, and cautious, analysis that addresses all concerns in the present, material and non-material, O'Connell brings up some necessary thinking points. However, the issues he addresses are those that are assuming archaeologists are trying to find spatially distinguishable activities, which is not a realistic goal for interpretation, except in extremely rare circumstances.

Carr (1984) outlines this last point by stating that archaeologists should use models that meet three conservative-approach assumptions; (1) any or all effects from behavioral and archaeological formation process are present at the site, (2) it may not be possible to determine which constraining effects are present at the site, such as spatial and temporal constraints, and (3) spatial analyses should be able to cope with these constraints. Although these are necessary assumptions, he admits that it is possible in practice to ascertain what processes contributed to site formation and that techniques with limitations in regards to the aforementioned assumptions are effective in some cases. Ultimately, these models seek answers to two types of questions, inferential and operational, in which the former addresses the extent and organization of sites on the larger scale and the latter addresses smaller scale questions of clustering of specific types within the assemblage (Carr, 1984). On a similar note, Bartram et al. (1991) and O'Connell (1987) posit that most archaeological excavations are far too small to fully understand site structure, which can make interpretations problematic. Thus, it is necessary to be cognizant of these spatial constraints when considering site structures.

3-ETHNOARCHAEOLOGY

Many different ethnoarchaeological works show the various behavioral patterns concerning different groups and how they use space. The vast majority of these studies focus on hunter-gatherer and forager groups, which potentially are more accurate analogs to how our ancestors used space prior to the advent of agriculture and the onset of their growing sedentism. Understanding extant human space use provides archaeologists with

the best relational and formal analogues for interpreting anthropic spatial patterning at archaeological sites (see Gifford-Gonzalez, 1991, for analogy discussion). The following review examines studies of extant human groups from several geographic areas, how each group's refuse production is visible in spatial terms, and the implications of each group's spatial behavior.

To preface the following review, it is necessary to look at some assumptions that are typically taken into account when analyzing the space use of human groups. Kent (1984) outlines a few key assumptions that are typically employed while analyzing hunter-gatherer groups: (1) different activity areas can be discerned from the content and patterning of artifact and faunal remain assemblages, (2) most activity areas are sex specific, and (3) most activity areas are specific to one activity, or monospecific (though the latter two are more applicable for sedentary populations, as argued by Kent, but they are important nonetheless). Kent (1984) also has a few corollaries to these assumptions, including ideas that artifacts and bones are deposited where they were used, that refuse at activity areas can provide information on the areas function, that males and females do not usually use the same activity space, and that different functional activities are performed in different areas. It is important to recognize these assumptions when examining the spatial behavior of the following human groups.

The !Kung are a hunter-gatherer group in the Kalahari of southwestern Africa that live in small, short-lived camps during the rainy season and larger, more permanent camps in the dry season, though reoccupation of either type of site is possible in any season (Yellen, 1976; 1977; Brooks and Yellen, 1987). The sizes of the 16 sites that Yellen (1977) studied are based on the limit of the refuse scatter (ALS) and range from

59

59 to 581 m^2, with an average size of 222.4 m^2. Yellen (1977) observes that there are not

drastic differences in general site structure or space use between the transient camps and

the long-term base camps, which is also seen with the Nunamuit (discussed below:

Binford, 1983; 1978a). With this in mind, the analyses of each type of camp can be

included together, since the cultural material is generated in the same manner at each

place. Brooks and Yellen (1987) observe four ways in which primary refuse is generated:

(1) Procurement, which is gathering, hunting, harvesting, and collecting, (2) Processing,

which is butchery, peeling, cracking shells, and roasting, (3) Consumption, and (4)

Manufacturing, which is turning any non-food items into artifacts. Debris can also

become secondary refuse, where an area is swept and dumped to another area, disrupting

its original context.

Though each of these refuse generating activities create discrete patterns when

they happen, using sites continuously obscures each independent event and leads to

spatial redundancy, as discussed above. The !Kung are a prime example of a group that

reuses spaces over single occupations and reoccupies the areas repeatedly over many

years, which leads to what Brooks and Yellen (1987) call spatial redundancies. In the

!Kung camps observed, these redundancies resulted from observed patterns of spatial use,

in which many different activities take place in all different areas of the site, primarily

around hearths, and would overlap archaeologically (Yellen 1976; 1977). Many activities

occur in the central hearth area, including vegetable processing, food consumption, and

manufacturing everything except hunting weapons (Brooks and Yellen, 1987).

The potential for these recurring activities to obscure previous activity is greater

in the base camp areas than in the special activity areas, such as ambush hunting sites

(Brooks and Yellen, 1987). Reuse of areas within a site can happen on a daily basis, especially in areas around the central hearth and the material accumulates quickly over short periods of time, but generally from the same activities. Though reoccupation happens at many camp sites, Brooks and Yellen (1987) observe that the !Kung rarely reoccupy camps where the evidence from the past occupation is still visible because they may have exhausted the resources there in their previous occupation. This makes it much easier to obscure previous occupations because they may not choose the same spot for the hearth. Ambush sites are much different because they serve one main function and are small, so the activities at the site will be more localized and less diverse, creating a potentially more informative archaeological signal (Brooks and Yellen, 1987). Ultimately, many activities occur in places where people are living as opposed to the few, more recognizable activities that happen in special activity areas, which complicate archaeological interpretations.

Bartram et al. (1991) look at the camp use and spatial distribution of bone food refuse for the Kua San, also in the Kalahari. They observed four different types of occupations by the Kua San: (1) Base camps, which were larger camps and differentially occupied depending on the season (ALS: 34-761 m^2, averaging 380.5 m^2), (2) Transient camps, where people spent the night while traveling and created low-density debris scatters (ALS: 15-100 m^2, averaging 49.2 m^2), (3) Special purpose camps, where tasks surrounding large mammal butchery occurred and overnight stays had expedient shelters (ALS: 14-274 m^2, averaging 73.8 m^2), and (4) special purpose locations, which are much like special purpose camps, but no one stayed overnight (ALS: 14-100 m^2, averaging 44.8 m^2) (Bartram et al., 1991). The base camps differed depending on the season, with larger

dry season camps located within a traversable distance to water, and smaller rainy season camps located throughout their territory.

Bartram et al. (1991) discuss the formation of bone assemblages at these various occupation sites and observed a key seasonal difference regarding carcass acquisition: with there being a higher frequency of kills during the hot, dry season than during the cool, dry and rainy seasons. This difference is explained as being a result of only smaller sized animals being available during the dry season and larger migratory species were only present during the rainy season, so they would have to kill many more small animals to compensate for the lack of large animals during the dry season. Bartram et al. (1991) also observed five main carcass transport strategies that would affect bone assemblage formation: (1) Carrying the entire carcass back to the camp, which was for small animals only (duikers and steenboks) and mainly in the hot, dry season when water was scarce, (2) Carrying carcasses in partly disarticulated units, which was primarily done to small animals during rainy and cool seasons when water was not an issue and sometimes on larger animals if they were killed near camp, (3) Carrying select carcass parts, (4) Caching meat, and (5) Moving the camp to the kill sites. Large carcass processing far from camp often employed the latter three strategies, and mostly in some combination.

Primary bone accumulation occurred at the processing sites and the sites of consumption at all types of occupations, especially in and adjacent to hearths, where present. Meat-stripped marrow bones were typically broken and discarded at the processing site. Within the dry season base camps, the bones in and adjacent to the hearths consisted of primary deposits, the scatter near the hearth and bushes consisted of both primary and secondary, and the bones in the ash dumps were mainly secondary

refuse (Bartram et al., 1991). Contrary to the dry season camp patterns, secondary refuse was virtually non-existent at the rainy season camps, which was attributed to the brief occupation periods. The base camps during the cool, dry season consisted mainly of diffuse scatter, rather than clusters of bone (Bartram et al., 1991). The butchery site of an eland represented one observed special occupation site where most of the bones were scatters with some clustering near the hearth. Long bone shaft fragments clustered near the areas where the bones were broken, but hyenas removed most of the long bone epiphyses shortly after the site was abandoned (Bartram et al., 1991).

Although the camps of these two groups may vary seasonally and between each group, on the whole, they are still accumulating bones in a general pattern. Sites that are reoccupied multiple times are more likely to have attributes similar to palimpsests, especially base camps where multiple activities take place in overlapping areas. On the other hand, special activity areas in these groups show that reoccupation can increase the archeological visibility and, though the temporal spectrum is blurred, the activities are likely to be clearer.

Studies attempting to understand the use of space by East African foragers and hunger-gatherers are less abundant, but some valuable research exists on the Efe and the Hadza. Though there are several ethnoarchaeological studies on these groups, they also focus on butchery patterns, carcass transport, food-sharing, and central place foraging (similar to the interests in the many works on the !Kung). Although these studies do not necessarily exclude space use, they typically do not attempt to answer questions about space use on the outset; the answers to these questions are usually a corollary to the other questions they are asking. Nevertheless, their use of space is examined in select works.

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O'Connell et al. (1991) examine activity patterns of the Hadza, who are seasonal, central-place foragers in Tanzania. O'Connell et al. (1991) focus on patterning in base camps and the six base camps they studied range in size from 575 to 1250 m^2, with an average of 795.8 m^2. The authors observed that activity areas in the camps were routinely cleared of refuse, which created perimeters of secondary refuse on the exterior margins of the activity areas. Much like with the !Kung, the Hadza did not have strict spatial divisions of certain activities and there was significant overlap between all activities in the communal areas (O'Connell et al., 1991). Activities that occurred peripherally to the camps were more discrete, such as weapon manufacturing, but the likelihood of their archaeological signal preserving is far less than the communal area activities. During the daytime, the Hadza performed various activities mostly in the communal areas (85%) rather than in the household areas (15%), which is opposite of the trend observed in the !Kung and represents the main difference between these two groups (O'Connell et al., 1991).

The Efe represent a different environment than seen previously in the San and the Hadza, as they live in the dense forests of the Democratic Republic of the Congo. Fisher and Strickland (1989) studied several Efe camps over the course of a year and observed that some camps were used more than once, which was dependent on several factors, including their high residential mobility, each band's identification with a certain area of the forest, their close relationships with the Lese, and the location and ecological setting of each particular site. The sizes of the camps varied greatly: Based on 19 of the 30 sites, the sizes ranged from 44 to 532 m^2 and had an average size of 242.7 m^2. Most of the activities took place within the confines of the camp because the dense forests made

expansion of the sites difficult since more forest would have to be cleared, which makes the boundaries of the camps very well defined. As a result, every camp had a similar structure of a clear perimeter, huts, central open areas, fireplaces, and trash heaps, which were mainly located along the perimeter and behind the huts (Fisher and Strickland, 1989). The trash heaps are general in their contents and the central open areas of the camp sites are typically swept clean, except when a move is imminent and people care less about cleaning up, which leaves primary refuse during the terminal occupations of the sites.

Despite the environmental and geographic differences of the groups in Africa, there seems to be a general trend on a broader scale of site formation. Each group has a mixture of primary and secondary refuse, some more than others, and most activities and refuse deposit took place in the communal areas of the camps. Repeated occupation of sites by each group obscures the clarity of the occupation and activities are not confined to one area of the site, so there is much overlap of many different kinds of daily activities. The one exception to this is the special activity areas, which have only certain kinds of activities and are reused only for these activities, but the temporal clarity for these areas is not precise either. Ultimately, it is very difficult to discern small scale, discrete behavioral patterning both spatially and temporally, but it is possible to discern activities in a camp on a larger spatial and temporal scale, i.e. they took place at this general location over the time frame of multiple occupations.

Similar trends are seen through ethnoarchaeological studies of the Alywara, an aboriginal hunter-gatherer group of dry central Australia, who have now become more sedentary and dependent on the government for support. O'Connell (1987) observed their

household and special activity areas, which included more current activities like auto repair. The Alywara camps are quite large in size and population compared to more mobile foraging groups, ranging from 12,700 to 116,000 m^2, with an average size of 52,950 m^2, and the sizes of the camps can change over different occupations. The Alywara had many trash middens surrounding camp, with the denser accumulations being closer to the perimeter of the camp. The Alywara typically placed larger debris in the middens first, as primary refuse deposition, and smaller debris was more likely to be strewn about the activity areas, and the size of the middens were directly correlated with the size and duration of the camp (O'Connell, 1987). During long stays, the small refuse was typically swept to the edge to clear the activity areas, making it secondary refuse. When the Alywara stayed for long periods, the households and activity areas tended to shift around, their debris scatters eventually coalescing and becoming indistinguishable from one another (O'Connell, 1987). O'Connell (1987) also observed that the Alywara relocated base camps for both cultural and climactic reasons, including death, population decline, deterioration of houses, refuse build up, domestic strife, and weather, though the reoccupation of previously used sites was not addressed.

Cold weather hunter-gatherers have also been observed accumulating debris in different areas of their camps (Haakanson, 2000; Svoboda et al., 2011). Haakanson (2000) and Svoboda et al. (2011) studied bone deposition patterns of the Nenets, who are caribou herders in the Polar Ural Mountains in Russia. Svoboda et al. (2011) studied five sites, ranging from 240 to 7000 m^2, and averaging 2328 m^2. Svoboda et al. (2011) observed that the Nenets deposit caribou bones in their domestic and special activity areas, with most of the refuse deposition on the peripheries of the camps. Small

fragments of bones are typically found in the areas around their house structures, or chums, whereas larger bones are typically found in the periphery trash areas.

In addition to these patterns, Haakanson (2000) observed that there may be enough differences between winter and summer camps that archaeologists could confuse one culture for two. The main difference is that winter sites are on thick deposits of snow and less spatial integrity is preserved as the snow melts, in comparison to the summer sites where material is deposited and often remains in that exact location.

Binford (1978a, 1978b, 1983) has done extensive work on the Nunamiut Eskimo of northern Alaska, and made several observations regarding their sites and deposition of materials. Binford (1983) studied several specific site complexes, which were characterized by three main site types: hunting camps, kill sites with specialized areas for butchery, and stone caches where meat was stored. All three sites are locations of different activities, but they are all components of the same major task, in this case meat acquisition, and are used on the same day by the same people. For instance, Binford (1983) observed a 12 day butchery event of 50 caribou in a 1500 m^2 area that created two large dumps of broken bones from marrow extraction, and was composed of several sites surrounding the butchery area that could seem like many different sites archaeologically, but in reality were all part of the same larger task. Many sites were observed and only some were used multiple times throughout the year (Binford, 1983).

There are two main types of hunting camps; general hunting camps containing all members of the band, and lover's camps, where young couples were allowed to spend time alone away from the camp and also hunt (Binford, 1983). The range of size for all

hunting camps is not directly mentioned, but based on the scale of the figures in Binford (1983), they can be estimated to range from 250 to 1000 m^2. The general hunting camps observed were reoccupied many times over the past 100 years, resulting in palimpsests of activity, including multiple tent rings. Lover's camps had a much different debris scatter than other hunting camps due to the fewer people in the camp and the general activities that took place there (Binford, 1983). Lover's camps were utilized towards the end of the season when food supplies were depleting in order for the remaining food to be distributed to the older individuals and the younger people could hunt for themselves and help to support the hunt by spreading out through the larger landscape.

The kill sites were also specialized areas for butchery. Animals were typically shot at hunting stands and dragged to the butchery area. Binford (1978a) studied the spatial organization of the hunting stands and described two main areas of debris accumulation when the people sat in a semicircle around a hearth: the drop zone and the toss zone. The drop zone typically contained small fragments of bone from bone breakage that fell right where they were broken, basically where the person was sitting, whereas the toss zone contained larger, more complete bones and other items such as cans and tins that were thrown behind where the person was sitting once they were finished with them (Binford, 1978a; 1983). Depending on the wind direction, several hearths could be used over the time of the occupation, thus creating many overlapping drop and toss zones. The main hunting stand Binford (1978a) focused on, called the Mask Site, is approximately 90 m^2 and was used differently each time in terms of the layout and activities performed.

After the animals were killed, the activities were moved to the butchery areas, where a circle of debris typically surrounded the caribou, with other waste dispersing out along the periphery of the butchery area. Binford (1983) observed 111 caribou butchered in one area during a single hunting episode and later collected the bones that were left, calculating only an MNI of 54. Binford (1983) also found that hearths were created near the butchery area for the hunters to warm their hands and occasionally eat the marrow, leaving a completely different assemblage there than at other sites used concurrently. Stone caches were used to store meat that was to be dried and kept for future use, since they could not carry all of the meat with them. These were simply semi-permanent stone piles near the butchery site with meat interspersed (Binford, 1983).

Binford (1983) noted that behavior within the household itself was completely different; there were no toss or drop zones and the floors were regularly cleaned so there would be no evidence of the drop zone material. Binford (1983) also compared the Nunamiut to the !Kung and the Ngatatjara Aborigines, suggesting that they space their houses, sleeping areas, and hearths in a similar manner. Like the previous groups mentioned above, the Nunamiut have higher concentrations of material within the communal areas of the camps, though the resolution of each specific behavior is obscured over even short periods of occupation.

Murray (1980) surveyed various ethnographic works to examine discard locations of refuse in sedentary and hunter-gatherer societies, though she made no mention to the sizes of the sites examined. She noticed that the majority of sedentary societies discard refuse outside of their actual use locations, whereas hunter-gatherers discard refuse both at their use location and away from it, though the sample size she looked at for hunter-

gatherers is small (Murray, 1980). Migratory populations were also more likely to discard their refuse at the use site and were less likely to clear the activity areas of refuse, leaving most of the activity refuse in its original location.

Galanidou (2000) performed a similar survey of multiple forager and horticulturalists, though looks at cave and rock shelter use instead of open air camps. The sample included 35 sites from ten different groups in the Southern Hemisphere and they vary in site duration, long and short occupations, and type, such as camps, ossuaries, sacred sites, and manufacture locales (Galanidou, 2000). 32 of the 35 sites had measureable areas and ranged from 11.5 to 260 m^2 with an average of 64.7 m^2. Galanidou (2000) observed that specific refuse disposal was highly variable and largely dependent on cultural ideals. For instance, the Melpa of New Guinea believe that burning bones releases the spirits of the animals so instead of depositing them in the fire, they throw them out on the talus slope of the cave or in other special activity/deposit areas. Despite these cultural differences, all groups still accumulate various materials in or around the cave and there were even differences within the ethnic groups. Galanidou (2000) also noted that the hunter-gatherer sites were typically more minimalistic, with just a hearth and no real organization to the space, than the horticulturalist sites.

After examining these different groups, it is apparent that there are many differences in the way that people accumulate material, but there are some general trends. Many of the groups performed the majority of their activities in communal areas and near hearths. In these areas, people typically deposited smaller material in the areas where they worked, but larger material was deposited elsewhere, mainly at the periphery of the sites and in refuse areas. The long term camps typically would have less spatial

differentiation than short term camps because there would be more overlapping activities in the camps and more clearing of the material from the activity areas. The special activity areas, such as hunting stands or ambush sites, may provide the greatest insight for archaeologist, but they are probably the most difficult to locate due to their small size.

Ultimately, the differences in spatial behavior of the groups seem to be largely cultural, which was also noted by different authors (Kent, 1984, 1987; Murray, 1980; Galanidou, 2000). The only study of multiple groups in this paper that was based on primary research by one author (as Murray, 1980, and Galanidou, 2000, survey previous ethnographic works), Kent (1984), who looks at Navajo, Spanish-American, and Euroamerican families, with the latter two being more sedentary. Although different activity areas can be discerned while observing the groups in action, the potential archaeological visibility created by each group is quickly obscured by repeating activities daily and by cleaning up the activity areas. Kent (1984) concludes that modern hunter-gatherers, such as the !Kung, have far less sex-specific and monofunctional objects in their culture than the groups she studied, potentially due to a more egalitarian ideology. Sedentism, however, permits the accumulation of sex-specific and monofunctional objects, perhaps due to the accumulation of more objects in general.

As far as archaeological implications of the spatial resolution of various activities and areas, a few points come to the forefront. Though many sites are obscured by reoccupation and it may be impossible to discern the temporal aspect of many deposits, some sites retain a very clear spatial layout; mainly those short-term camps mentioned above where the activity surrounded a hearth and the areas were not cleared of refuse. Some sites of specific butchery events would also have a good chance of retaining their

initial deposit layout, depending on post-depositional processes, of course. The main

concern for recovering the most informative aspects about archaeological sites seems to

be the size of the excavations themselves. As demonstrated by several authors (Binford,

1983; O'Connell, 1987; Bartram et al, 1991; O'Connell et al, 1991), some camps are very

large and have smaller activity areas in the surrounding landscape, so archaeological

excavations only uncover a small portion of what is really going on in the area, even

including the shovel-test transects, though shovel tests offer an opportunity to locate the

extent of a site and interpolate the density of archaeological material throughout the rest

of the site. Though these are legitimate concerns, they are virtually impossible to rectify,

since archaeologists themselves are constrained by many outside factors, including

budgets, manpower, time, etc. The most important controllable factor of approaching an

accurate interpretation is diligent excavation and record keeping, which many sites are

privy to.

4-CARNIVORE BEHAVIOR

Humans are not unique in their ability to reuse and reoccupy sites over time and

create palimpsests, as some carnivores have similar material accumulating behavior,

though their material is limited typically to bone. The extant carnivores examined here,

hyenas and leopards, are known to accumulate bones in the same locations over certain

periods of time, and these locations are typically much smaller areas than where humans

live and deposit material.

4.1. *Hyenas*

Generally, each species of hyena accumulates material in two different areas: Latrines and dens. Latrines are specific areas where hyenas paste and defecate and are used by hyenas as a marker of territory, in which many, if not all, of the hyenas in a clan will leave their marks (Kruuk, 1972; Bearder and Randall, 1978; Mills, 1990). Long term latrines are those that are used repeatedly and short term latrines are only used once (Mills, 1990; Bearder and Randall, 1978). Mills (1990) observed that about 80 percent of brown hyena latrines in Gemsbok National Park in Botswana and South Africa were used only once (short term), and they were located throughout the clan's territory. Most of the long term latrines were only used for short periods of time, though some were used for many years, including one that was used for 12 years (Mills, 1990).

Bearder and Randall (1978) studied spotted hyenas in Timbavati Private Nature Reserve in South Africa and quantified the feces found at various latrines. They found that short term latrines, i.e. those used only once, averaged 10 scats and were typically one to two meters in diameter and they found that the 57 long term latrines observed were highly variable, but no size variation was mentioned (Bearder and Randall, 1978). The majority of the long term latrines were located at various 'landmarks' in the territory, including certain trees and bushes, intersections of their walking paths and rivers or roads, and there was no indication of seasonal use. Some of the latrines were used for several years, one of which had 144 scats, and some were used heavily for a while, abandoned, and then used again at a later date (Bearder and Randall, 1978).

Spotted hyena latrines are typically large (>100m^2) and located outside their dens by at least 20 meters whereas brown and striped hyenas can have latrines located both inside and outside of their dens and they are demarcated with clear boundaries (Skinner and van Aarde, 1981; Brain, 1981; Berger et al., 2009). Kerbis-Peterhans and Horwitz (1992) studied a striped hyena den (approximately 180 m^2) in the Negev Desert of Israel and found a latrine located in an area of the cave away from the major bone accumulations, though some bones were present. The latrine was next to a natural rock in the cave that the hyenas perched on while defecating (Kerbis-Peterhans and Horwitz, 1992). Though latrines are the main accumulation areas for hyena feces from each species, evidence of defecation is not confined to latrines, whether they are inside or outside the dens, and feces has been observed inside and around dens of all species, but not in any specific pattern. Latrines do not typically contain bone accumulations either, with the exception of some scattered bones around within-den latrines. Thus, there are clear differences between the various contexts, leading to different contextual interpretations of coprolites in the archaeological/paleontological record.

Like latrines, dens are used by all hyena species and there are several different types of dens. The use of the dens, and ultimately the bone accumulation within the dens, is quite variable depending on the species of hyena. Several studies report that brown and striped hyenas accumulate more bones because they bring bones back to dens to supplement the diet of the young and they are more specialized bone cracking scavengers than the spotted hyena, which is a more capable hunter and brings food portions to young less frequently (Skinner et al., 1998; Lansing et al., 2009; Pokines and Kerbis-Peterhans, 2007; Mills and Mills, 1977; Mills, 1990; Henschel et al., 1979; Kruuk, 1972; Owens and

Owens, 1979). These behaviors result in different bone accumulations, both in density and in the taxon represented, but the general use of the dens is quite similar.

There are two main types of hyena den that can be in either caves or burrows (or in human-made structures, such as wells or crawl spaces; see Pokines and Kerbis-Peterhans, 2007, for discussion on this): birth, or natal, dens and communal dens. Birth dens are smaller than communal dens as they are where one pregnant female gives birth to her cubs and they stay in this den away from other hyenas for the first few weeks to few months of their lives (Boydston et al., 2006; Cooper, 1993; East et al., 1989). After spending the first part of their lives in the birth dens, cubs are then moved to the communal dens of the clan with other cubs in order to socialize them into the clan and the social hierarchy (Cooper, 1993). Communal dens are described by Boydston et al. (2006) as those used by two or more females at a time. Though this is largely the trend for all hyenas, there is some variability. Communal dens can also be used as birthing dens and natal dens can be used by multiple females simultaneously, though Boydston et al. (2006) reported that 80 percent of the spotted hyena cubs they observed were born in isolated natal dens, and 89 percent of natal dens studied were used by one mother at a time. East et al. (1989) found a similar majority of females that gave birth away from communal dens (70%) in the 20 spotted hyenas that they studied.

Communal dens are also locations that hyenas often use repeatedly and over large expanses of time. Boydston et al. (2006) found that 29 of the 57 communal dens that they observed were used multiple times, which falls into the reoccupation category (as described by Brooks and Yellen, 1987). Though many of the dens were used two or more times, they found that only a few were used several times and seemed to be the most

popular. Pokines and Kerbis-Peterhans (2007) examined a cave den (approximately 48m^2) which was abandoned when they began work there in 1998 but the excavations were cut short in 1999 when they found a live juvenile hyena in the back of the den, again evidence of reoccupation, though this could have been simply a natal den.

Many of the dens also can be categorized as reuse (as defined by Brooks and Yellen, 1987), since hyenas continuously occupied these sites for great lengths of time. Mills (1990) observed that spotted hyenas in Kruger National Park in South Africa occupied dens for over six months and sometimes for several years, though the hyenas in Gemsbok National Parks in Botswana and South Africa occupied dens for a much shorter time frame (45 days on average), potentially due to the presence of fleas. Kruuk (1972) observed similar den use behavior in the spotted hyenas of Serengeti and Ngorongoro National Parks in Tanzania, with an additional observation that large dens were typically used for longer periods than small dens, which is most likely due to the large number of families in the large dens and the constant rearing of cubs of all ages (large versus small dens refer to the number of cubs and adults using the dens, not the actual area, which is not mentioned by the author). Boydston et al. (2006) followed a clan of spotted hyenas in Maasai Mara National Reserve in Kenya for ten years and observed that dens were used for an average of 31 days before the hyenas moved, with many dens being used for only a few weeks and some as long as eight months. Brown hyenas have also been observed occupying the same dens at different times (Mills and Mills, 1977)

Since a large amount of time is spent at communal and natal dens, dens become important areas of bone accumulation. All species of hyena provision their young to some extent, though striped and brown hyenas tend to bring more food back to their

young and accumulate more bones than spotted hyenas. Through many examinations of various hyena den assemblages, some general trends become apparent. The bone weathering of many of these assemblages is primarily in the lower stages of weathering (see Behrensmeyer, 1978, for stages) indicating quick removal of these bones from exposure to the elements and/or quick burial: At Lake Eyasi spotted hyena den in Tanzania, 75 percent are stages 0 to 1 (Prendergast and Domínguez-Rodrigo, 2008); at a spotted hyena cave den in Maasai Mara National Reserve, Kenya, 93 percent are stage 0 (Pokines and Kerbis-Peterhans, 2007); at a spotted hyena den at Syokimau Gorge in Kenya, 73 percent are stages 0 and 1 (Egeland et al., 2008); at a hyena den, possibly spotted, at Koobi Fora, Kenya, 95 percent are stages 1 and 2 from area just outside the den (Lam, 1992); at a striped hyena den in Kashan, Iran, 71.5 percent are stages 0 and 1 (Monchot and Mashkour, 2010). Though weathering is not an indication of hyena specific behavior, it is helpful in determining the depositional history of the bones within the assemblage and provides useful insights into the amount of time that the bone was exposed on the surface.

Dens tend to follow a general trend in their spatial distribution as well. In most cases where the spatial pattering was reported, a large density of bones occupied the center area of the den and bones scattered out from there, with less dense accumulations on the periphery and near the entrance (Hill, 1983; Sutcliffe, 1970[1]; Brain, 1981; Lam, 1992; Monchot and Mashkour, 2010; Henschel et al., 1979). This is a rather obvious distribution, since caves and burrows are irregularly shaped or rounded and accessibility to the peripheries is limited. This point is actually quite helpful for determining the extent

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[1] Though one of these dens is quite different.

of a site in the archaeological record but it increases the likelihood of palimpsests, since the limited space constrains the potential depositional area and multiple species of animals can also contribute to the assemblage because hyenas eventually abandon their dens. Though the temporality of the site may be obscured, the taphonomy of the assemblage can provide some clarity to the depositional processes, since large proportions of the bones will have tooth marks and other evidence of carnivore activity, including digested or regurgitated bones. Earthen dens typically have a shorter lifespan than cave dens because they are more prone to collapse, which would preserve the bones within the den as they were deposited, but they tend to have considerably less bones than cave dens (Pokines and Kerbis-Peterhans, 2007; Lansing et al., 2009).

Bone accumulation at these den sites varies greatly and is a result of several factors including duration of den occupation and amount of hyenas using the den. Although these data are very important for understanding bone accumulation factors of hyenas, the latter factor is rarely known or reported. Egeland et al. (2008) surveyed an abandoned spotted hyena den at Syokimau Gorge in Kenya and concluded that the assemblage that they collected spanned ten or more years of accumulation based on weathering stages, though they did not observe the occupation period or the hyenas in the den. Monchot and Mashkour (2010) noted that it was not possible to assess how many striped hyenas occupied the den that they studied in Iran. Henschel et al. (1979) observed six spotted hyenas using the four dens that they studied, but did not specify the duration of occupation and only collected surface bones scattered outside the Natab den (approximately 70 m^2) due to inaccessibility. Pokines and Kerbis-Peterhans (2007) could not identify the duration or the number of spotted hyenas at the Maasai Mara den.

Though this makes a true understanding of hyena bone accumulation quite difficult, the nature of the research itself creates many other logistical problems that are inherent to this type of field observation and does not allow for many of these factors to be quantified. Many of the hyena dens are found by park rangers and are come upon after the occupation, some are occupied by a certain number of hyenas, but very intermittently. Perhaps it is important to concede these shortcomings of the research and work with what has been studied extensively and draw qualitative inferences. For example, more hyenas in a den for longer periods of time leads to more births and juveniles throughout the duration of the den, in turn leading to more bone accumulation from provisioning their young. Therefore, finding the extent of the dens spatially, if possible, and examining the taphonomic signatures of the assemblage are the best ways to begin interpreting the sites. With this last thought in mind, it is surprising how few studies report the area or extent of the dens (e.g. Kruuk, 1972; Lam, 1992; Boydston et al., 2006; Egeland et al., 2008; Prendergast and Domínguez-Rodrigo, 2008; Monchot and Mashkour, 2010) and it makes it very difficult to fully understand how hyenas use space, since there is no dimensional data to relate to the spatial distributions of the accumulations.

In addition to den accumulation, some experimental studies on hyena bone preference also offer valuable insights into how hyenas accumulate bones. Binford et al. (1988) put several bones out in different locations in Kruger National Park, South Africa, where hyenas were known to scavenge. Spotted hyenas moved all of the bones from their original locations and three of the four locations showed that hyenas deleted bones with marrow intact. Marean and Bertino (1994) performed a similar study, but on captive spotted hyenas in Berkeley, California where the space that they could move the bones

was constrained. They found that limb bone shaft fragments without marrow moved the least and limb ends moved the most, leading them to state that long bone shafts may be the best indicators of the original location of the breaks. They also suggest that limb bone ends should be eliminated from spatial analysis where there is also carnivore activity because they are likely not in the same position that they were originally deposited (Marean and Bertino, 1994). Marean et al. (1992) performed another experiment at this same hyena enclosure in order to test the efficacy of the schlepp effect hypothesis. In this experiment, when presented with axial or appendicular elements, hyenas first chose axial elements, then the less dense bones, and lastly the densest bones. The authors concluded that this behavior could be misconstrued as the schlepp effect and it is not completely reasonable to assume that an assemblage of just limb bones can only be attributed to human agency (Marean et al., 1992). Many of these behaviors can assist in the interpretation of the fossil assemblages.

4.2. *Leopards*

Considerably less study on bone accumulation activity has been done on other carnivores, such as felids and canids. Despite this paucity of research (or reporting), leopards frequently store kills in trees out of the reach of other predators (though storing behavior can vary by geographic location, see, e.g., Karanth and Sunquist, 2000) and less frequently they use rock shelters and caves as 'lairs' where a larger accumulation of bone is possible. Primarily, studies of leopards and their bone collecting behavior focus more on the types of prey species that leopards prefer, which is mostly size class 1 and 2 and

some size class 3 and juveniles of even larger animals (Brain, 1981; Cavallo and Blumenschine, 1989; Smith, 1978; le Rouix and Skinner, 1989; Grassman Jr., 1999).

Though these studies do not all explicitly state the spatial patterning implications of leopard behavior, some inferences can be discussed nonetheless. De Ruiter and Berger (2000) collected faunal remains from a leopard made assemblage in the dolomite caves of John Nash Nature Reserve in South Africa. A female leopard used the cave (approximately 164 m^2) as storage and feeding locale and accumulated eight medium and large sized antelopes, a caracal, and two porcupines, which the authors documented in 1991 and returned to see post-depositional changes in 1998 (de Ruiter and Berger, 2000). A ledge (roughly 8 m^2) in the cave separating both the upper and lower chambers and the front and rear of the cave contained five of the specimens, and the remainder of the specimens were scattered about the rest of the cave, with little overlap between specimens. This site offers an interesting insight into how much a leopard can accumulate in one place over a relatively short period of time. Brain (1981) offered a model of leopard accumulation in caves, stating that leopards would store kills in trees above caves and the debris would fall down into the caves. Though this is still possible, de Ruiter and Berger (2000) show that it may not be as complicated as that; perhaps leopards stored their kills in the caves themselves.

Caves, however, do not represent the primary location where leopards bring their kills in many geographic areas. In Africa, leopards use trees far more often, but the accumulation at these sites is highly variable. Leopards maintain small territorial ranges for long periods of time, so the opportunity of using the same trees to store kills is possible, but to what extent goes unreported (Cavallo and Blumenschine, 1989). In

addition to variable tree use, the spatial clarity of tree kills is not as favorable as caves, since bones falling from trees are more likely to scatter, whereas cave assemblages preserve more spatially discrete information if left untouched. In addition to spatial scatter, trees are short lived in comparison with caves. Ultimately, more studies need to be employed on leopard spatial behavior to really understand if and how the bone accumulation is affected by their space use.

5-DISCUSSION

Humans and carnivores alike accumulate bones and material in specific areas, though there is a certain degree of variability in how that happens. Based on ethnoarchaeological data, humans are prone to deposit material in the areas that they live, and the material is deposited in specific areas. Generally, if the occupations are short term, then there is a greater chance that the material will remain in its original position where it was used; and if the occupations are long term, there is a greater chance that the material will be mainly secondary deposition, since the floors area routinely cleared of debris and long term camps tend to have middens and trash heaps on their periphery. Reuse of specific areas for specific tasks increases the potential for high resolution archaeology, whereas reoccupation of camps will more than likely obscure the archaeological imprints, mainly because the organization of the camp will undoubtedly change. Special activity areas, such as hunting stands, ambush locations, and butchery sites, offer valuable insight to highly specific depositional events, but, due to their small

size and short term occupations (with the exception of some observed ambush sites that are used repeatedly for years), the there is a low likelihood of recovering the sites.

Similar patterns of deposition can be seen in the carnivores. Hyenas deposit material in areas where they live: dens. Though most kills do not make it back to the dens, bones deposited in dens are more likely to preserve and these assemblages often result from repeated use. Dens used for longer periods of time are more likely to retain much more information than those used only once for a short period of time. Like humans, hyenas abandon their dens for periods of time, only to return later and begin a new depositional phase, which leads to a palimpsest. Leopards can repeatedly use dens as well, though the literature on this is far less robust than the hyena literature.

Site formation is inherent in the discussion of how each of these respective groups of mammals deposits material. Life history also plays a major role in site formation, not only for carnivores but for humans as well. The life history patterns of carnivores impacts site formation in a more obvious way, especially in hyenas, since adults provision their young and have different dens for different time periods in the juvenile's life. Though it is more subtle in human populations, life history directly impacts site formation because various tasks are completed by different individuals of different sexes and ages. The spatial clarity is not as apparent in human camps as compared to carnivore assemblages, since the variation of activities is far greater in a human encampment. Life history and site formation are quite inter-related, but other factors also contribute to and affect site formation.

One of the ubiquitous site formation issues that is apparent in all biotic accumulations is that of time averaging and palimpsests. Time averaging can result from many different taphonomic factors, both biotic and abiotic (see Lyman, 1994 and 2008, for discussion), but here I am specifically referring to the reuse and reoccupation of sites that leads to temporal obscurity and the creation of palimpsests. In the most basic terms, time averaging is a result of deposits over a certain period of time, i.e. days, weeks, years, etc., within the same stratigraphic unit. Caves are often time averaged, because in many cases it is difficult for new sediment to enter the cave so years and years of material can pile up and appear to represent a short depositional time frame. Inevitably, archaeological site interpretations will acknowledge the potential for a palimpsest and concede that the site is a result of many years of occupation. These reoccupations can even result from different accumulation agents, such as alternating occupations of a cave by hominins and carnivores. This issue is clear even in the ethnoarchaeological and actualistic examples above and it is unavoidable; the question is now, "how do we work around it?"

In order to begin to address this question, we have to identify many questions regarding scale. Is it more important to try to determine if one animal was butchered at this specific locus or do we want to understand a broader behavioral use of this space? Clearly, the material and stratigraphy of the site will allow only certain scales to be assessed, but it is a matter of identifying the spatial and temporal constraints from the onset that will guide the interpretations. For many sites, less specific questions need to be pursued, such as 'is there evidence of one or several activities here?' or 'were most of the material depositing activities located in a specific area?' When looking at the broader scale, general conclusions can be drawn from the material and spatial layout, such as

locations of hearths, trash heaps, or middens at human sites or an area of a hyena den that was used more for a latrine than for depositing bone.

With regards the questions addressed in the outset, it is possible to discern various activities at sites and where they took place. Site formation is inherent in the discussion of material accumulation; carnivores and humans have very similar accumulation behaviors in the sense that they both will deposit material where they are currently living, though the nature of the material will be quite different. Some patterns created by humans and carnivores are observable within fossil assemblages, but the temporal resolution of such sites may be less clear. Though many sites are palimpsests, many other sites show evidence of discrete depositional events, such as animal butchery or flint knapping. Regardless of the amount of material at the site, the importance of the information derived from the assemblage will be a result of the questions one is asking. In the following analyses, these ideas play an important role in reconstructing site formation at Dmanisi.

PAPER 2:

Spatial patterning of the archaeological assemblage at Dmanisi, Georgia: An analysis of site formation and carnivore-hominin interaction in Block 2

SUMMARY

The spatial aspects of site use have been well documented ethnoarchaeologically and archaeological sites from as far back as the Lower Paleolithic have been interpreted as the result of organized behavior. Similarly, certain carnivore species habitually inhabit the same living spaces in extant and paleontological studies. This study uses theoretical and analogous frameworks for the interpretation of site formation and spatial behaviors of carnivores and hominins in the B1 strata at the Early Homo site of Dmanisi, Georgia.

Several aspects of the stones and faunal material are analyzed in order to determine if any spatially distinct behaviors can be identified and located. Taphonomic sub-assemblages are compared to the overall distribution of the faunal material and any deviation from this distribution could be an indication of differential space use. Only the coprolite distribution is significantly different from the overall distribution of faunal material. Extant studies on hyenas have shown that each species defecates in specific areas, both inside and outside of their dens. Other lines of taphonomic evidence reconstruct more complex inter-specific competition that likely led to the accumulation of bone, but this study provides new evidence to supplement these interpretations. Hominins appear to be a small part of the contributing factors to site formation.

1-INTRODUCTION

Recently, using geographic information systems (GIS) to assist in interpreting site formation of archaeological and paleontological assemblages has become more commonplace, as many studies incorporate GIS tools for spatial analysis at Paleolithic sites (e.g. Alperson-Afil et al., 2009; Discamps et al., 2012; Galotti et al., 2012; Espigares et al., 2013; Gabucio et al., 2013; Oron and Goren-Inbar, 2014). This study uses the versatility of these analysis methods to investigate the spatial patterning of stones and faunal material and the implications for carnivore-hominin interaction at the early *Homo* site of Dmanisi, Georgia.

Many spatial analyses of archaeological sites focus on establishing clusters of archaeological material in different areas of the site (e.g. Alperson-Afil et al., 2009; Galotti et al., 2012; Oron and Goren-Inbar, 2014). In perhaps the most illuminating example, Alperson-Afil et al. (2009) used distributions flint microartifacts to determine that the burned portion of the assemblage clustered in two main areas, therefore leading them to locate potential hearths in the absence of preserved charcoal and conclude that hominins at Gesher Benot Ya'aqov "were organizing their living spaces by 790,000 years ago."

Within Block 2 at Dmanisi the distribution of stones and faunal material is primarily localized in one area (~25m^2) with concentrations differing slightly within each stratum. With such a dense deposit of bones that largely resulted from depositional forces other than abiotic processes (i.e. fluvial or colluvial deposition), we are interested in examining other aspects of the stones and faunal material to sort through these large

clusters. Therefore, our question now shifts to how different aspects of the stones and faunal material are distributed as compared to the overall distribution. In other words, if stones and faunal material are stratified into different sub-assemblages (e.g. carnivore modified versus hominin modified bones), do the distributions of these sub-assemblages differ from the overall distribution of stones and faunal material? Parsing out these data allow for an effective comparison between agent-specific taphonomic factors in which multiple biotic site formation processes can be examined.

1.1. *Background*

The site at Dmanisi is situated on top of a promontory at the confluence of the Masavera and Pinezauri rivers in the Kvemo Kartli region of Georgia (Figure 2.1). Though several different areas of the Dmanisi promontory have been excavated in recent years, Block 2, the focus of this paper, has been excavated since the mid 1990s and is currently being expanded. Consisting of primarily ash layers, the fossil bearing deposits date between 1.85 and 1.76 Ma, with the older sediments (A) being of normal polarity and the younger sediments (B) being reverse polarity (Gabunia et al., 2000; Lordkipanidze et al., 2007; Ferring et al., 2011; Messager et al., 2011; Nomade et al., 2016).

The B1 stratum in Block 2 is the main focus of this analysis, as it is the most prolific layer, and produced all of the hominin bones to date (Figure 2.2)[2]. Despite its

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[2] It is necessary to note here that this stratigraphic profile is used as a background in nearly all profiles, but this is for a general guide. The bones and stones in profile do not necessarily belong within the strata that they appear against on the profile, wince there is high variability north and south of the 62N line.

higher elevation, B1 represents the oldest layer, which is a relatively flat, *in situ* ash layer while other parts of B1 are further divided into sub-strata that represent younger pipe/gully fill sub-strata: B1z, B1x, and B1y. Erosional contacts are present between B1z and B1 and between B1z and B1x. The lowest of the B1 deposits, B1y, is a remnant of either pipe fill sediments or the first phase of gully fill. B1x and B1z are interpreted as gully fill, and B1 and the rest of the upper B sediments are ashfalls (Ferring et al., 2011).

Though B1 is dispersed throughout Block 2 and is present over much of the other excavation areas on the Dmanisi promontory, the pipe/gully fill sub-strata are constrained in their distributions for a few different reasons (Figure 2.3a). B1x and B1y are largely constrained by the dimensions of the basalt depression that is located in the northeast portion of Block 2 and they are bounded by higher elevations of basalt in the south and west, with an overhang present in the west (Figure 2.3b). Furthermore, the pipe and/or gully features in which they were deposited have clear contacts with A strata. Additionally, a vertical slab of basalt, located at 62m N and 66-67m E, disrupts the distribution of B1x and B1y, which is especially apparent in B1x since it extends further east than B1y. Due to its higher elevation, B1z is less constrained by the basalt formations (Figure 2.3a) and more dependent on the gully boundaries, which are evidenced by sharp erosional contacts on the margins with B1. Medieval storage pits, or ormos, are located throughout Block 2 (Figure 2.4), but only a few are deep enough to disturb the B1 strata, including one that is present in the northeast portion of Block 2, which potentially deleted a large amount of stones and faunal material throughout each of these B1 strata. These factors are the principal controls on the distribution of pipe/gully erosion and sedimentation, and the subsequent bone accumulation in these areas.

Now that these constraints are identified, spatial data, including 3-dimensionally plotted specimens, are analyzed here in order to assess spatial distributions and detect distinct spatial patterns of the stones and faunal material. Taphonomic and geologic analyses (e.g. Lordkipanidze et al., 2007; Tappen et al., 2007) hypothesized that the fossil bearing deposits are largely autochthonous with little evidence for fluvial action or abiotic post-depositional movement, and are supported by examining orientation and dip , bone refits, and fragmentation (Coil et al., Paper 1). Thus, we examine one main question using analytical methods that addresses our overarching spatial question outlined above: Do spatial patterns indicate differential deposition of faunal material by biotic agents, which includes hominins, carnivores, and large rodents (e.g. *Hystrix*)? Ultimately, if abiotic site formation processes are largely ruled out as responsible for the bone accumulation, perhaps we can use spatial relationships of taphonomic indicators of behavior to assess the potential for differential space use by carnivores, hominins, or large rodents. Specifically, are there notable differences in distributions of sub-assemblages of the faunal and stone assemblages and do these distributions differ based on strata?

At many other sites, spatial analyses have revealed interesting patterns and associations of specific sub-assemblages of the archaeological and paleontological material (e.g. Alperson-Afil et al., 2009; Gabucio et al., 2013; Oron and Goren-Inbar, 2014). Additionally, spatial patterning is used to supplement interpretations of carnivore-hominin interactions, primarily between mid-Pleistocene humans and hyenas (Discamps et al., 2012; Enloe, 2012; Espigares et al., 2013). Taphonomic data – relying primarily on overlapping surface modifications and comparisons to actualistic research – typically is

used to assess the timing of carcass access. However, spatial distributions can also reveal patterns indicating the timing of carcass access. For example, Espigares et al. (2013) investigated *Pachycrocuta brevirostris* coprolites and a lithic artifact scatter in proximity to a partial *Mammuthus meriodonalis* skeleton at Fuenta Nueva-3, Orce, Spain, and they observed that many coprolites are present where the front limbs would have been located, concluding that the hominins must have removed those skeletal elements prior to hyena access to the carcass. Though the interpretive resolution at most sites is not as high as in this example, valuable spatial relationships regarding carnivore-hominin interaction are evident.

2-METHODS

This analysis includes archaeological data from Block 2 found between 1992 and 2011, as excavations since 2012 have concentrated on B2-B4 layers. As a result, squares that are north of the 64N line and east if the 69E line have yet to fully expose B1 strata. Despite this, squares between 63-65E have reached B1x and B1y and a few others have uncovered some B1 deposits (Figure 3); thus, they will be considered here with the caveat that these are preliminary data in these locations. 3D coordinates are based on a local datum and were collected manually by excavators until 2002, when we upgraded to a total station (Trimble).

The stratifications of the data are based on taphonomic data collected by Tappen and her students and basic stone categorizations by Medea Nioradze (See Mgeladze et al., 2011, for lithic analysis). Bone surfaces were examined under angled light with at least

10x magnification. Stone material is subdivided into basic categories of cobbles, lithic artifacts (which includes stone tools and flakes), and cores. Further analyses of the stone material will allow for a more extensive spatial analysis, but general statements about spatial patterning are still made here.

Many different traces of biotic agents are found on the bones within the assemblage. The taphonomic data are used in tandem with the spatial data to determine if there are particular areas of the assemblage where like-taphonomic processes are clustered, e.g. cut-marked bone, carnivore chewed bone, etc. The most interesting clusters of these data would be assemblages that cluster independently of the overall distribution. Interpretations of the agents of bone modifications were assigned to three certainty levels based on their similarity to known modification traces: 1) certain, 2) probable, and 3) possible. Only agent-specific modifications identified to the highest confidence level are used here, as they are the least ambiguous. Likewise, differences between the density distribution of stone and faunal material could inform on differential space use, both within and between each layer. Therefore, we analyze the spatial patterning and the relationships between assemblages in order to identify potential concentrations of agent-specific traces.

Multiple different analysis methods are used to examine the spatial patterning. Distribution maps simply show the layout of the excavated stones and faunal material. Spatial analysis techniques are employed to understand the spatial patterning. Kernel densities are used to calculate the densities of items around each output raster cell by using a weighted search radius, where the highest values are at the location of the point and the edge of the search radius has a value of zero. The values of the output raster cells

thus represent the sum of all values that are within the search radius. Kernel densities are generated using the Kernel Density tool in ArcGIS 10.2, where the search radius is 50 cm and the resulting cell size of the raster output is 1 cm. The specifications for the kernel density analysis follow parameters from Alperson-Afil et al. (2009) and Oron and Goren-Inbar (2014) due to comparable sizes between their excavation areas and Block 2, as opposed to following methodology from spatial analyses on much larger areas, such as at Schöningen (Böhner et al., 2015). Also in the interest of comparison with other sites, we standardize the kernel density outputs by dividing all values by the highest density value, which allows for comparison across all sub-assemblages (Alperson-Afil et al., 2009; Oron and Goren-Inbar, 2014). This makes for effective comparisons of datasets regardless of sample size. For this process, the raster generated by the Kernel Density tool was subsequently run through the Divide tool in the Raster Math toolbox in ArcGIS 10.2.

Some subsets of the stone and faunal assemblages show different distributions than the overall patterns of their parent assemblage. Two parent assemblages are used for these comparisons: the stone assemblage and the faunal assemblage, which includes both bones and coprolites. In order to determine if these differences are statistically significant, we employ chi-squared tests. The application of this method is based on Alperson-Afil et al. (2009; also employed by Oron and Goren-Inbar, 2014) and tests sub-assemblage distributions against the overall distribution of the parent material. Specimen counts within each sub-square ($0.25m^2$) were compiled for each of the sub-assemblages. In Block 2, there are 444 total subsquares, but each layer has a different distribution so different sub-squares were used. For example, the specimen counts and subsequent

statistical tests for B1x and B1y use only 74 sub-squares, since those are the only squares

with faunal material. Chi-squared tests were then run using the following equation:

$\chi^2 = \Sigma_i (OBS_i - EXP_i)^2 / EXP_i$; where 'i' is the number of excavated units and the null

hypothesis is that there is no statistical difference between the overall stone and faunal

distributions, which serve as the expected (EXP) densities, and the sub-assemblages (e.g.

coprolites, carnivore bones, etc.) being compared (Observed densities; OBS). The sum of

the resulting values should be less than the critical value (CV) at the $p=0.05$ level for the

null hypothesis to be supported. If the resulting probability was below the 0.05 threshold,

we calculated the standard residuals (SR) for each sub-square ($SR = OBS_i - EXP_i / \sqrt{EXP_i}$)

to determine what was driving the difference (See Haberman, 1973). SR calculations

result in both positive and negative numbers, where results below -2 (lower densities than

expected) and above 2 (higher densities than expected) are considered to be significant

values that do not support the null hypothesis.

3-RESULTS

The distributions of all bones in B1 layers of Block 2 show dense accumulations

in the base of the excavation area in B1x and B1y (Figure 2.5). The kernel density maps

indicate that the densest portions of accumulation are in B1x and B1y, between 63 and 65

m east and at elevations around and below 1015 m, which coincides with the area just to

the east of the basalt overhang (Figure 2.6). The expected distribution of any sub-

assemblage (e.g. herbivores, carnivores, etc.) should mimic the overall distribution of the

faunal assemblage; thus the null hypothesis is no difference between distribution patterns.

As expected, carnivore bones, herbivore bones, and carnivore modifications follow this

pattern (Figure 2.7, 2.8, and 2.9, respectively). In contrast, the distribution of coprolites

shows a much different pattern, as coprolites are most dense in areas that have low

densities of bones (Figure 2.9). Specifically, coprolites are found at similar elevations as

the highest densities of bones, but they are mainly located between 65 and 66 m east and

further north than the highest densities of all bones. The coprolite distribution in B1x and

B1y is the only sub-assemblage where the chi-squared test resulted in a statistically

significant difference from the overall faunal distribution (χ^2=583.43, p<0.0001), further

supporting the observations based on the kernel density maps. The SR values are shown

in Figure 2.10. Rodents of all sizes gnaw bones before and after burial, but few species

are capable of accumulating large quantities of bone; at Dmanisi, *Hystrix* is the only

possible bone collecting rodent. Bones exhibiting evidence of rodent gnawing are spread

randomly throughout the B1 layers, both horizontally and vertically, though the majority

are located in B1 (25/44, or 57%; Figure 2.11). A further analysis of rodent gnaw patterns

should elucidate which sizes of rodents gnawed on the bone at Dmanisi.

When examining the stone distributions, the majority of the material is located in

B1, though clusters are not as apparent as we see in the faunal material (Figure 2.12 and

Figure 2.13)[3]. Some stone material is present in the base of the B1 deposits, but it is far

outnumbered by the faunal material. Using the broad lithic artifact classification system

and the initial attributions by M. Nioradze, further distributions are analyzed by each sub-

assemblage. Cobbles tend to follow the overall stone distribution, with a steady

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[3] It should be noted that the density estimates treat the points as if they were on a flat surface, which is one limitation of the Kernel Density tool. For example, the high density in Figure 2.13b near 67E is an artifact of the 12m depth of lithic material in squares all along the 67E line. This distribution is apparent in plan view, which is why both maps are used in tandem. This issue is even more apparent in Figure 2.15b, which is why the distribution map is also shown (Figure 2.14b).

distribution throughout all of B1 (Figure 2.14 and 2.15), though there is a cluster in B1y as cobbles make up over half of the stone material found in that stratum (101/189; 53.4%). Lithic artifacts, however, are spread throughout B1, but are sparse in B1z, B1x, and B1y, represented by <6 specimens each (Figure 2.16 and Figure 2.17). Cores and hominin modified bones, though scarce, are concentrated in the lower elevations, mainly B1y and B1x, and are randomly scattered in B1 (Figure 2.16).

4-DISCUSSION AND CONCLUSIONS

Generally, differential patterning of some stones and faunal material is apparent depending on the stratigraphic layer. Much of the differential distribution is a result of the dimensional constraints of the pipe and gully features in the B1 strata. Specifically, the stones and faunal material have similar distributions in B1 and B1z, but there is a much larger accumulation of bone in B1x and B1y. The relationships between different categorical distributions in these lower elevations offer some opportunity for inference on hominin-carnivore interaction, especially in B1y and B1x. The cumulative evidence in B1y is thus: (1) High density of bones, including carnivore bones, (2) highest density of bones exhibiting carnivore surface modifications, including tooth marks, broken bones attributed to carnivores, and digested bone, (3) relatively low amount of stones, (4) few hominin modified bones and cores (<6), (5) very few lithic artifacts (<5), and (6) relatively high density of cobbles compared to other strata (Table 2.1). With this evidence, along with the presence of dozens of coprolites, it is reasonable to infer that carnivores accumulated much of the faunal material.

Two hypotheses could explain the hominin impact on this assemblage: (1) In some cases, carnivores scavenged from hominin utilized carcasses and brought them to this spot or (2) hominins entered this area to scavenge on carnivore kills. In support of the first hypothesis, very few lithic artifacts that could have a functional association with the hominin modified bones (i.e. flakes, stone tools, and possibly cobbles) are in B1y, along with the presence of more carnivore bones and carnivore modified bones. The specimens that have been categorized as cobbles are the subject of a forthcoming analysis that tests hypotheses regarding their mode of acquisition and deposition (Ferring, 2015). Some may be manuports, but not all (see Mgeladze et al., 2011)[4]. In any case, their direct association with many small bones that do not exhibit evidence of transport is an important line of evidence that establishes a critical control on transport energy. In addition to the lithic artifacts, skeletal elements attributed to two hominin individuals are in B1y (Lordkipanidze et al., 2007).

Though there are coprolites in B1y, the highest density is in B1x, where they are clustered between 65 and 66 E, 62 and 64 N, and 1014.5 to 1015 m of elevation, which is just to the north of a large, vertical basalt slab. Relatively low densities of other bones are located in this area compared to the rest of B1x, where the majority of the bones are located either one meter to the west or just south of the basalt slab. Some studies on extant hyena behavior show that hyenas differentially use space when defecating, either in designated latrines on the landscape or in certain areas of their dens (Hughes, 1958; Skinner et al., 1980; Skinner and van Aarde, 1981; Brain, 1981; Kerbis-Peterhans and Horwitz, 1992; Berger et al., 2009). The cluster in B1x contains 40 coprolites in a ~4 m^2

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[4] Mgeladze et al. (2011) reports that the majority of the cobbles are manuports, but considerably more analyses are needed to confidently contend that supposition (Ferring, pers. comm.)

area, which account for nearly half of all coprolites found throughout the B1 strata. This potentially represents informative evidence regarding differential space use by carnivores, since the basalt creates a natural wall between two areas of the deposit. Like B1y, B1x exhibits a paucity of cutting tools but cobbles are present throughout the layer, though in a lower relative abundance compared to B1y. As a result, the interpretation of carnivores as agents of bone accumulation in B1x is similar to B1y.

In both of these layers, canids are the most prevalent carnivore, followed by felids, ursids, and hyaenids. Some of the hyaenid specimens are from juveniles based on fusion states and dentition, but not at the frequency one would expect if it was solely a hyena den, though there is high intra- and inter-specific variation in studies of extant hyenas (Tappen et al., 2007, 2011, 2013; Cruz-Uribe, 1991; Pickering, 2002; Domínguez-Rodrigo and Pickering, 2010; Kuhn et al., 2010). In addition, juvenile carnivores from other families are present (Tappen et al., 2007, 2011, 2013, 2015). Erosional pipes have been observed to have lifespans of years to a few decades (Ferring, 2014) and extant analogs of carnivore species (primarily hyenas) are highly mobile, moving in and out of dens through different parts of the year and abandoning dens after a short use-life (Kruuk, 1972; Mills, 1990; Boydston et al., 2006), where they can be subsequently occupied by other animals. Evidence of predation on other carnivores, (i.e. carnivore modifications on ursid, canid, and felid bones) is also present in B1y and B1x, which offers potential insights into interactions between carnivores at this time period.

In contrast to B1x and B1y, B1 shows much more dispersed distributions of stones and faunal material, though the material is primarily located in the northeast portion of the excavation block. Certainly, some areas have higher concentrations than

others, but some of these gaps in distributions are a result of the location of medieval

storage pits, especially in the southwest portion of Block 2 (Figure 2.4). Each bone and

stone sub-assemblage follows the distribution of their parent assemblage, and there are

less dense clusters of bone than what is seen in B1y and B1x. The differences in the

distributions of stones and faunal material are likely due to less spatial constraints in B1

as compared to B1y and B1x, where basalt acts as a primary control on deposition,

essentially confining the B1y and B1x deposits to a ~20m^2 area between 62-68E and 59-

64N. The highest frequencies of cobbles, lithic artifacts, and debitage are located in B1,

along with the highest count of cores. Thus, the hominin activity in this layer is

considerably larger than what is seen in other strata.

The B1z material is concentrated in a ~12 m^2 area, which is constrained on the

east and west by the walls of the gully, and on the northwest by the extent of previous

excavations from the 1980s (Figure 2.4). B1z has lowest counts of stones and faunal

material out of all the B1 strata, and each of the sub-assemblages follow the distribution

of their parent assemblage.

Clearly, different bone accumulation processes contributed to deposition in each

layer. The dynamic paleo-landscape at Dmanisi is likely responsible for the contribution

by multiple species to the accumulation. Tappen et al. (2007) described the situation as a

predatory hot-spot with a strategic location on a peninsula surrounded by a vital water

resource, not only for prey species but for predators as well. The stones and faunal

material in B1y are primarily concentrated under and directly east of the basalt overhang,

likely exposed by a pipe or gully, which would have served as a protected location for

any predator to use as a den, or simply as a place to feast upon a recently acquired

carcass. B1x has a similar distribution, but also has a vertical basalt slab that separates the northern and southern areas of the layer, which offers another potentially protected area. B1 and B1z do not have such protected areas, which could explain why the accumulations are more randomly distributed throughout B1. B1 and B1z certainly show evidence associated with carnivore modifications, but not to the concentrated extent that we see in B1x and B1y. Logically, if carnivores did not have a safe place to repeatedly consume carcasses or raise young, one would expect there to be a less dense concentration of bones, as our data show.

The faunal material from B1x and B1y represents the strongest evidence for contribution to the accumulation of the assemblage by specific biotic agents. Hominins and carnivores exploited resources on this dynamic landscape, and the latter likely took advantage of secluded areas to consume acquired carcasses and possibly raise young. Using spatial analysis methods on taphonomic variables, we can begin to sort through palimpsests of various site formation processes and tease out differential distributions of certain aspects of the assemblage. Block 2 offers a small glimpse into this short window of time, informing on broader carnivore-hominin interaction likely taking place elsewhere on the Dmanisi promontory.
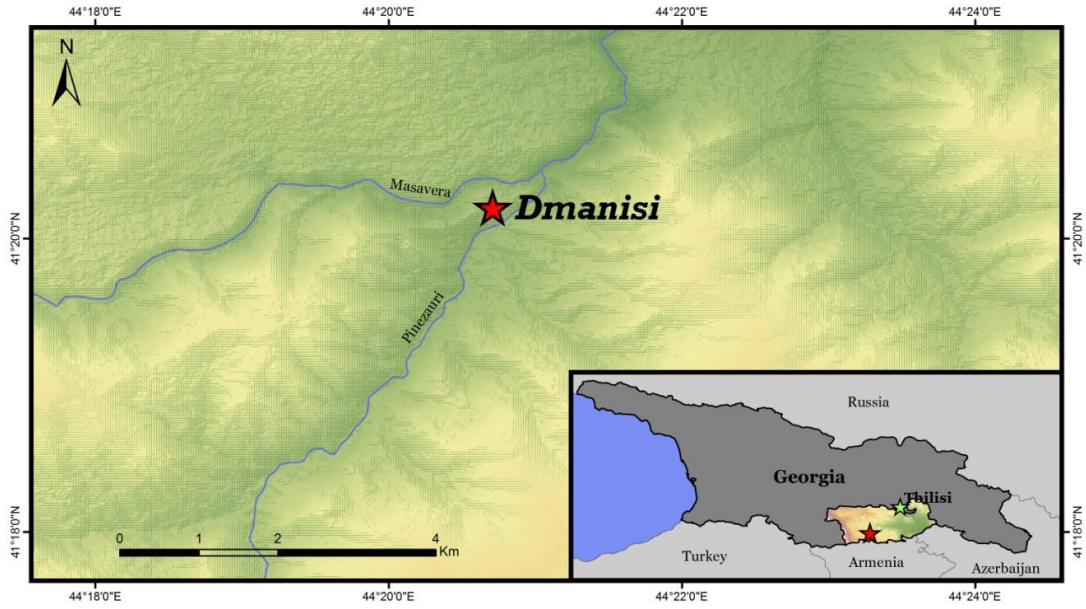
Figure 2.1: Map of Dmanisi and location within Georgia (inset).
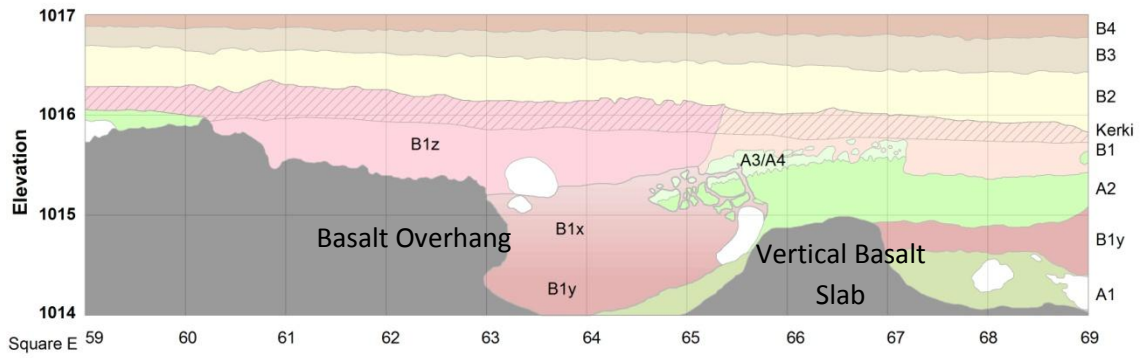
Figure 2.2. Stratigraphic East-West profile at 62N line in Block 2 highlighting the basalt overhang and vertical basalt slab that are described in the text. Adapted from Ferring (unpublished data).
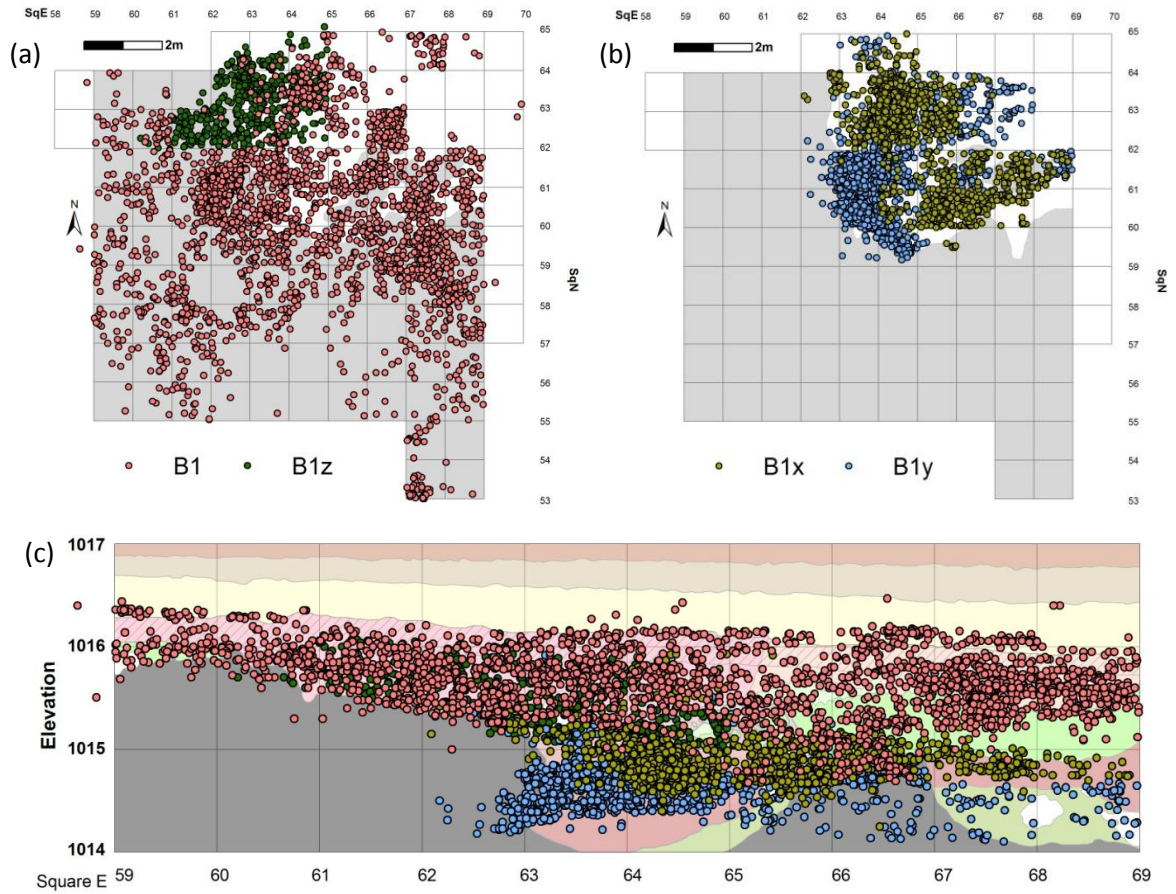
Figure 2.3. (a) Distribution of stones and faunal material from B1 and B1z, (b) distribution of stones and faunal material from B1x and B1y, and (c) East-West vertical profile of distribution of stones and faunal material all B1 strata. Refer to legends in (a) and (b) for the color codes of each layer.
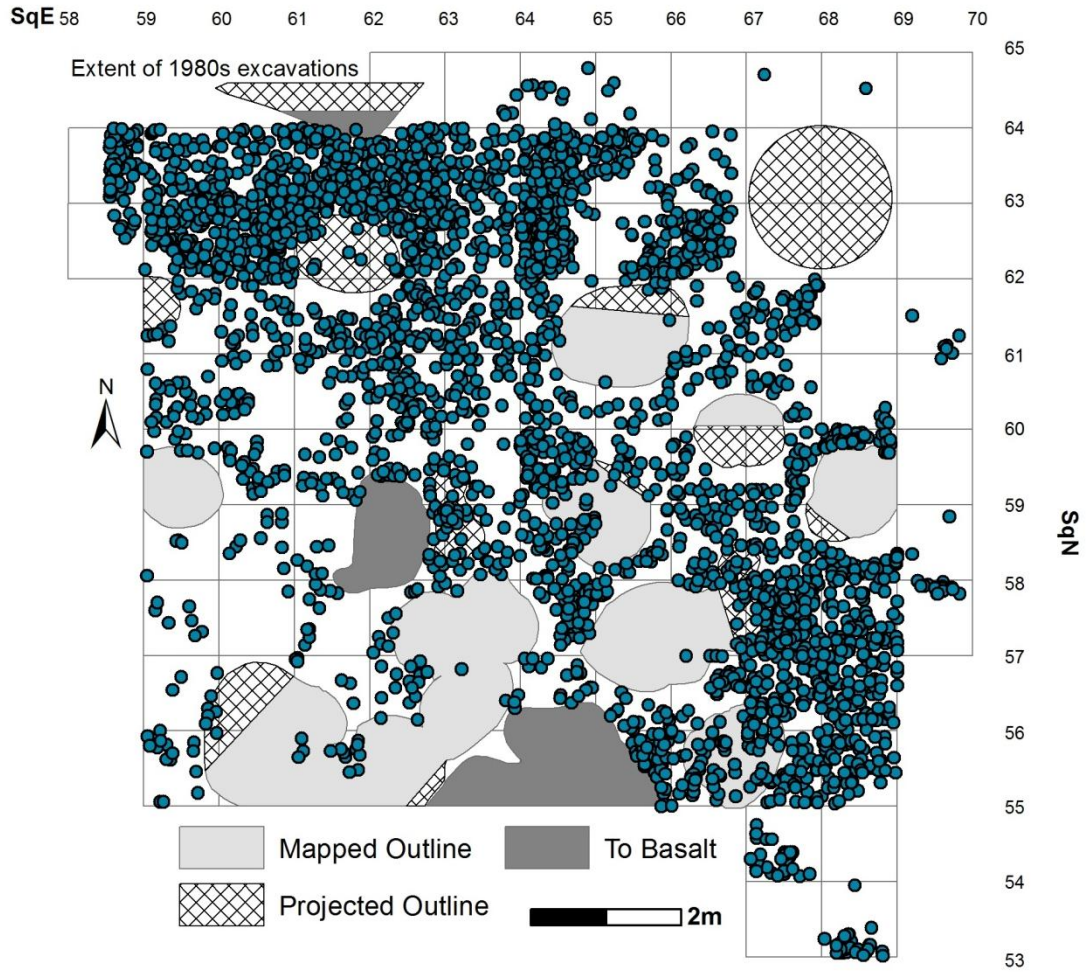
Figure 2.4. Locations of Medieval storage pits (ormos) plotted with the stones and faunal material from B2, which is a stratum from a higher elevation than the B1 strata. Most ormos disrupt the distribution of the stones and faunal material in B2, but strata in lower elevations are less affected.
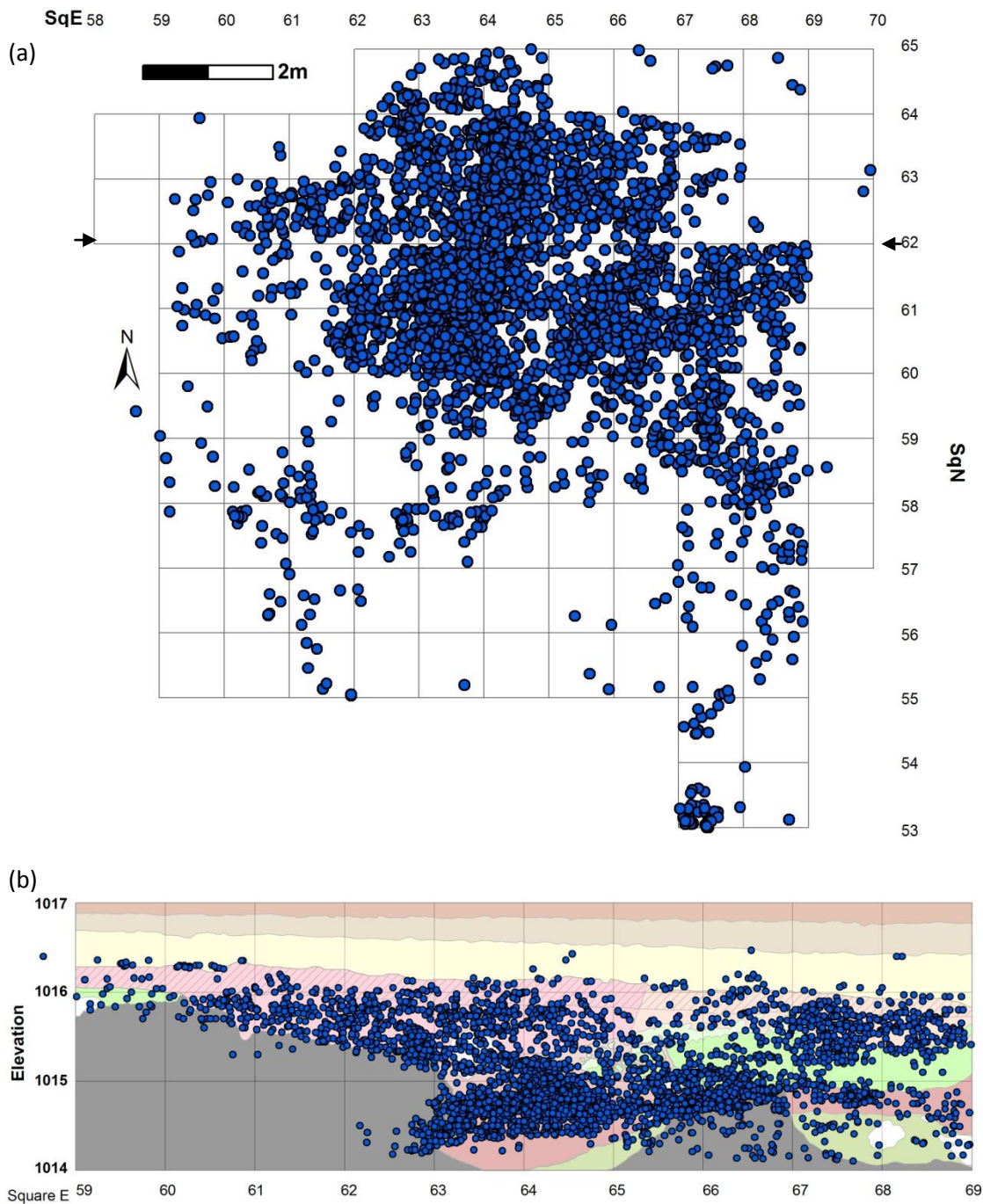
Figure 2.5. Distributions of all bones (*n*=3888) in B1 strata of Block 2 in plan (a) and East-West profile (b). One square = 1 m^2. The arrows in (a) indicate the location of the stratigraphic profile used as a backdrop in (b). The thickness and architecture of the sediments vary over short distances both north and south of the 62N profile, so each bone shown in that profile is not necessarily within the strata on which it is displayed, since it could be as much as 9 m away.
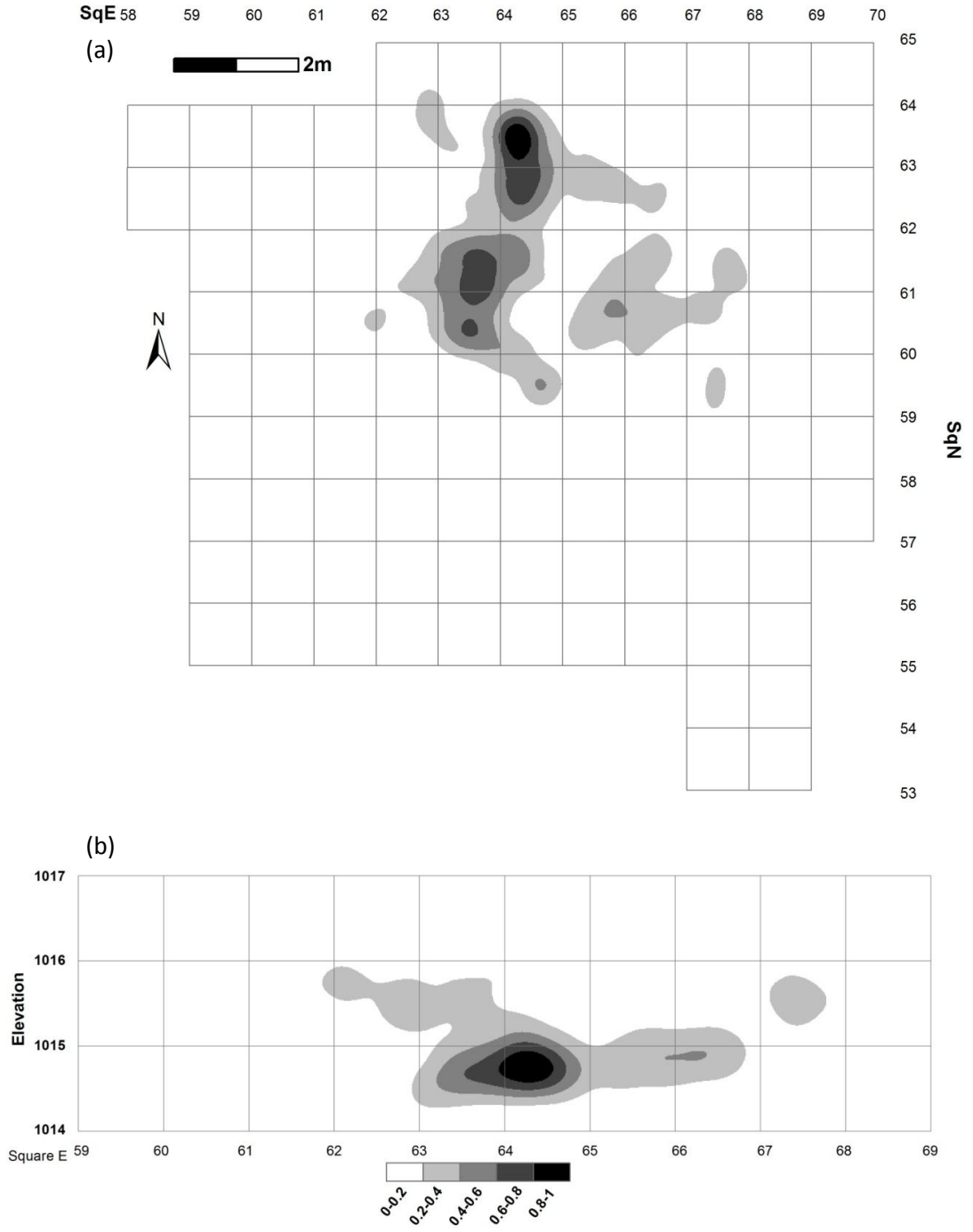
Figure 2.6. Kernel densities of all bones (*n*=3888) in B1 strata of Block 2 in plan (a) and East-West profile (b). One square = 1 m^2.
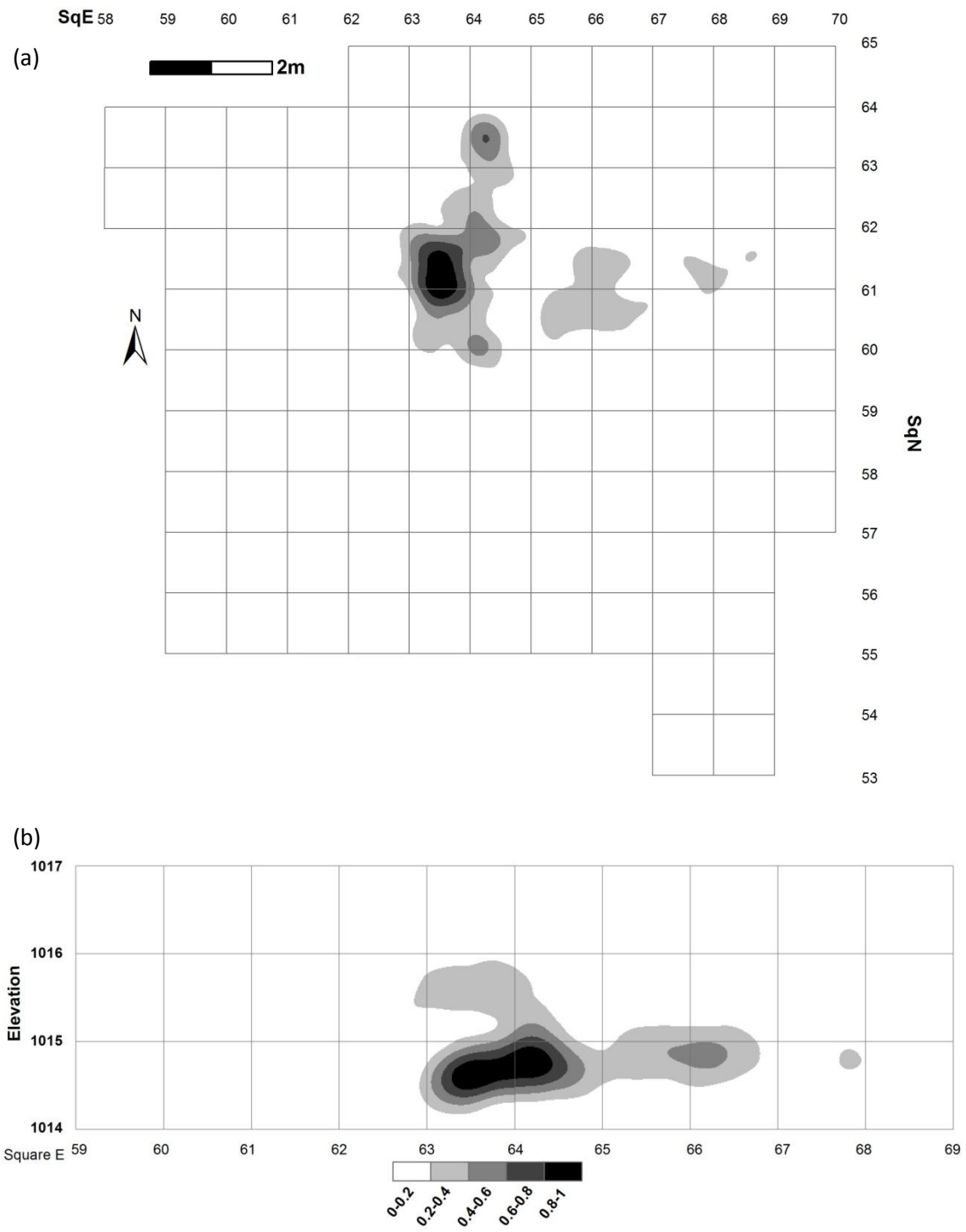
Figure 2.7. Kernel densities of carnivore bones (n=480) in B1 strata of Block 2 in plan (a) and East-West profile (b). One square = 1 m^2.
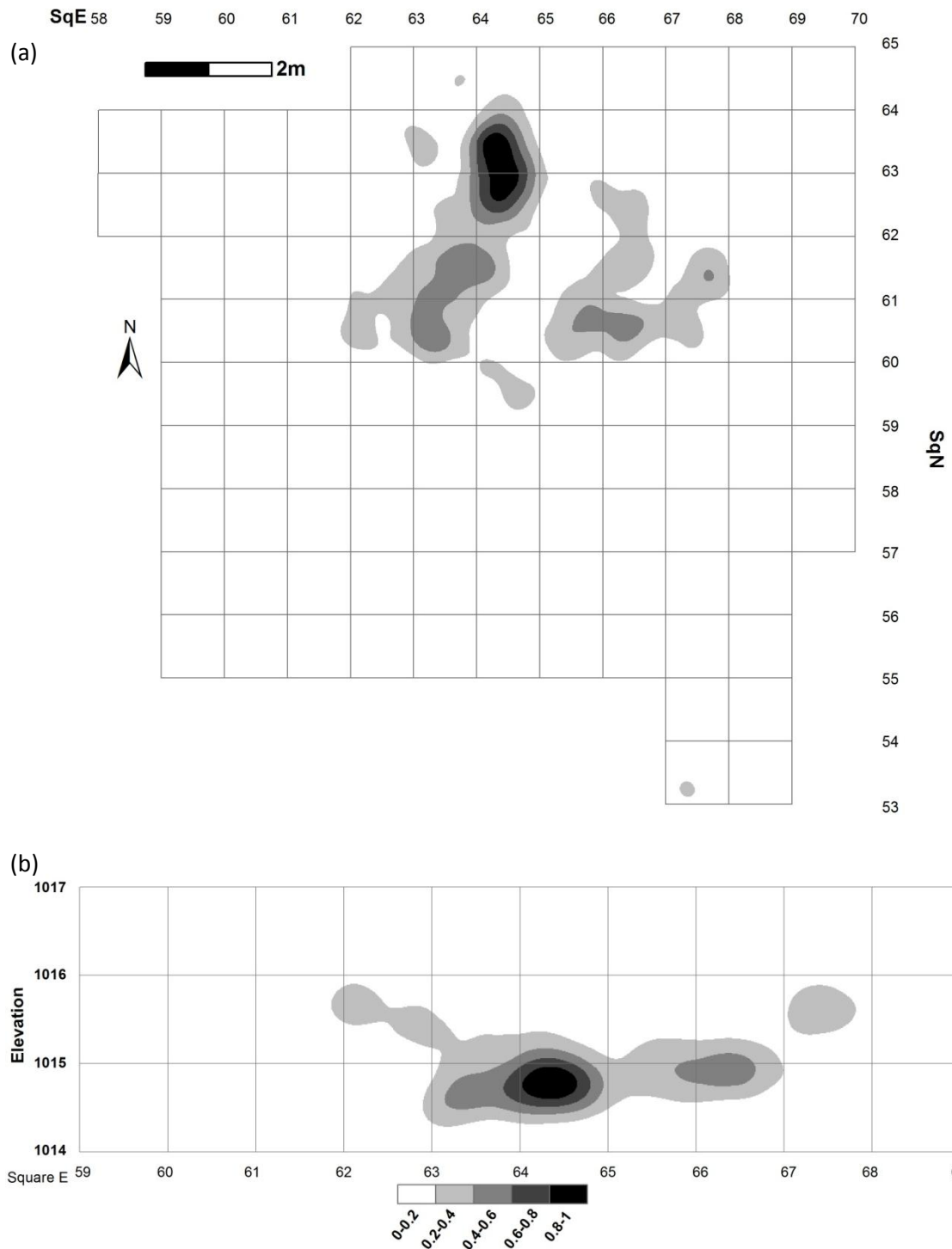
Figure 2.8. Kernel densities of herbivore bones (*n*=1514) in B1 strata of Block 2 in plan (a) and East-West profile (b). One square = 1 m^2.
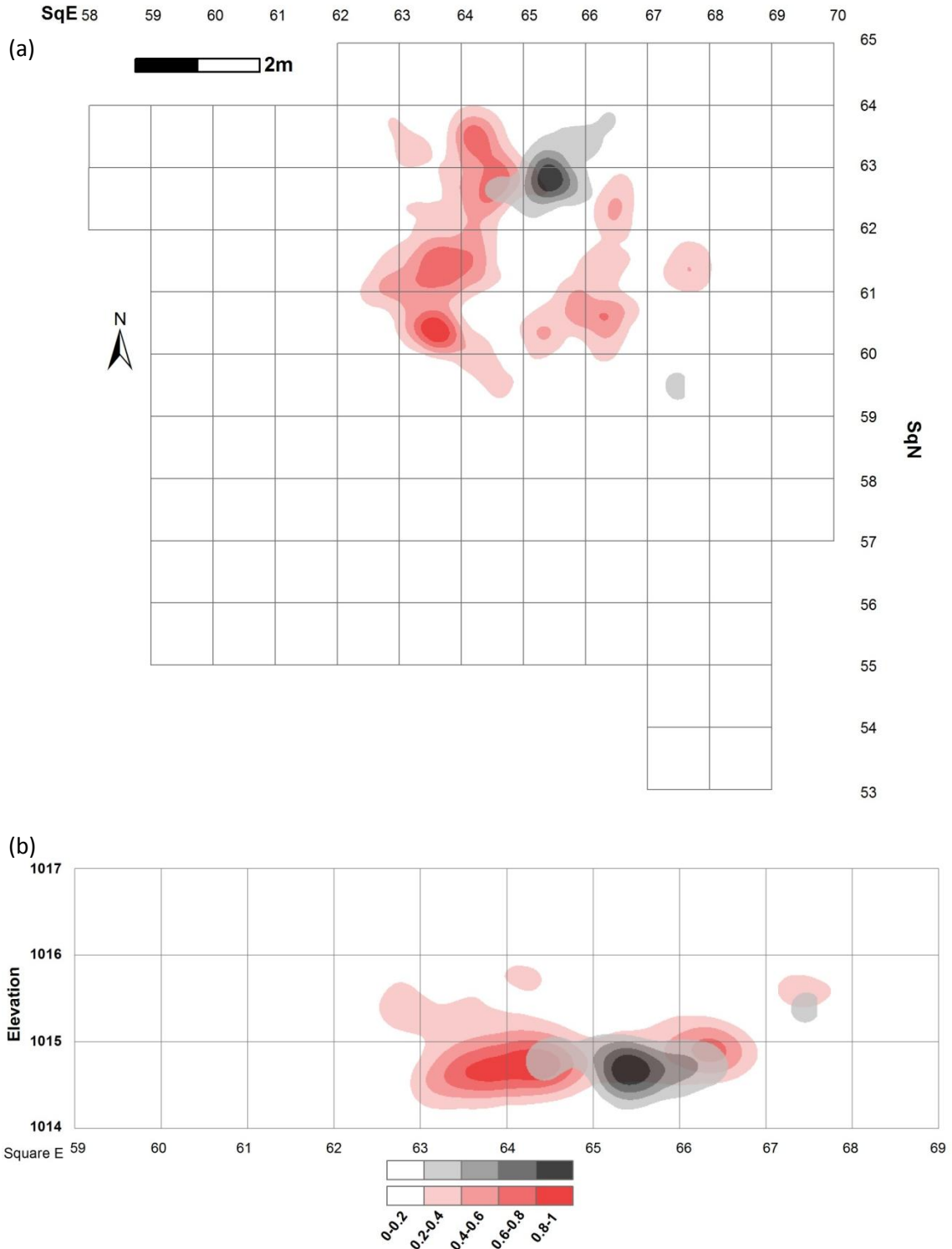
Figure 2.9. Kernel densities of carnivore modified bones (Tooth marks, carnivore broken bones, and digested bone: *n*=591) and coprolites (*n*=96) in B1 strata of Block 2 in plan (a) and East-West profile (b). One square = 1 m². Red scale represents carnivore modified bones and gray scale represents coprolites.
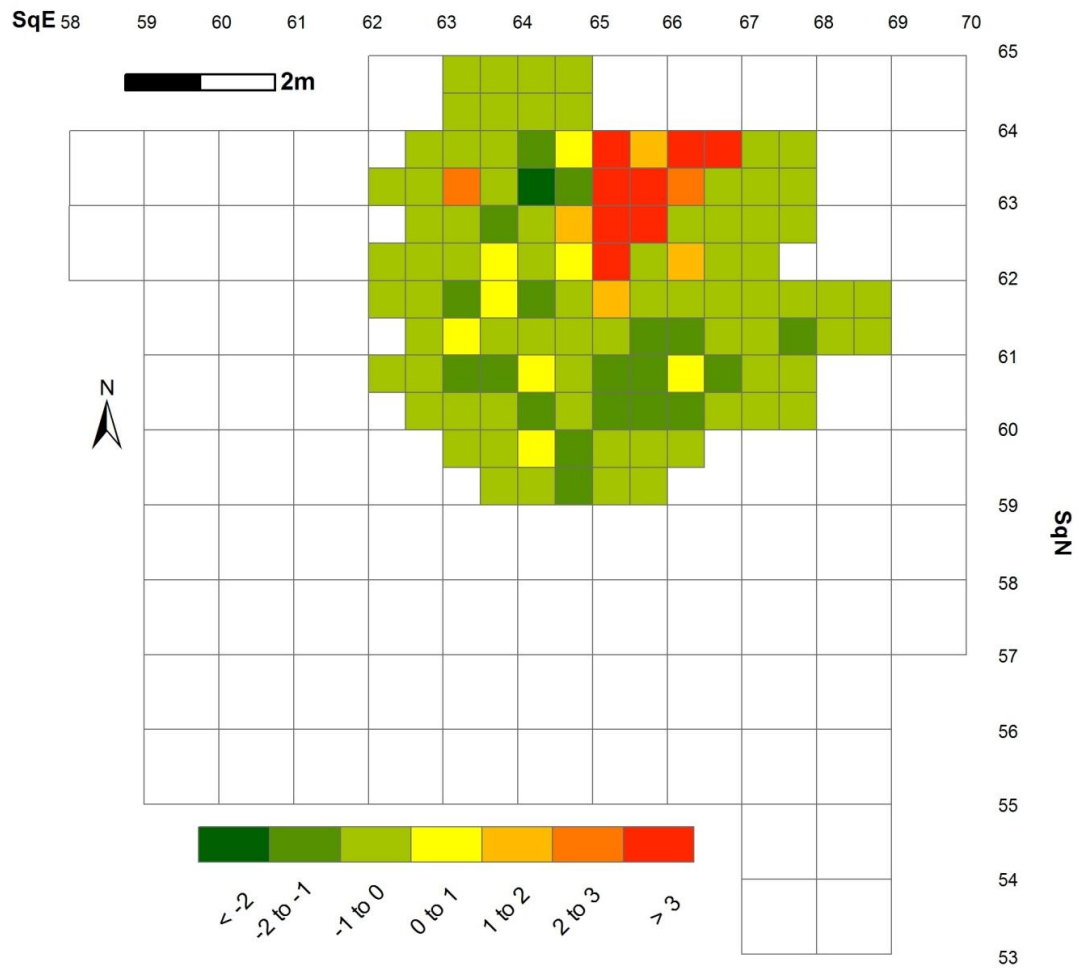
Figure 2.10. Standard residual values for the coprolites in B1x and B1y (*n*=74) tested against the expected distribution of all bones and coprolites in B1x and B1y (*n*=2225). SR values less than -2 and greater than 2 have *p*-values <0.05 and are considered significantly different in their densities than the parent material to which they are being compared. Faunal material from these two strata are only found within these colored squares.
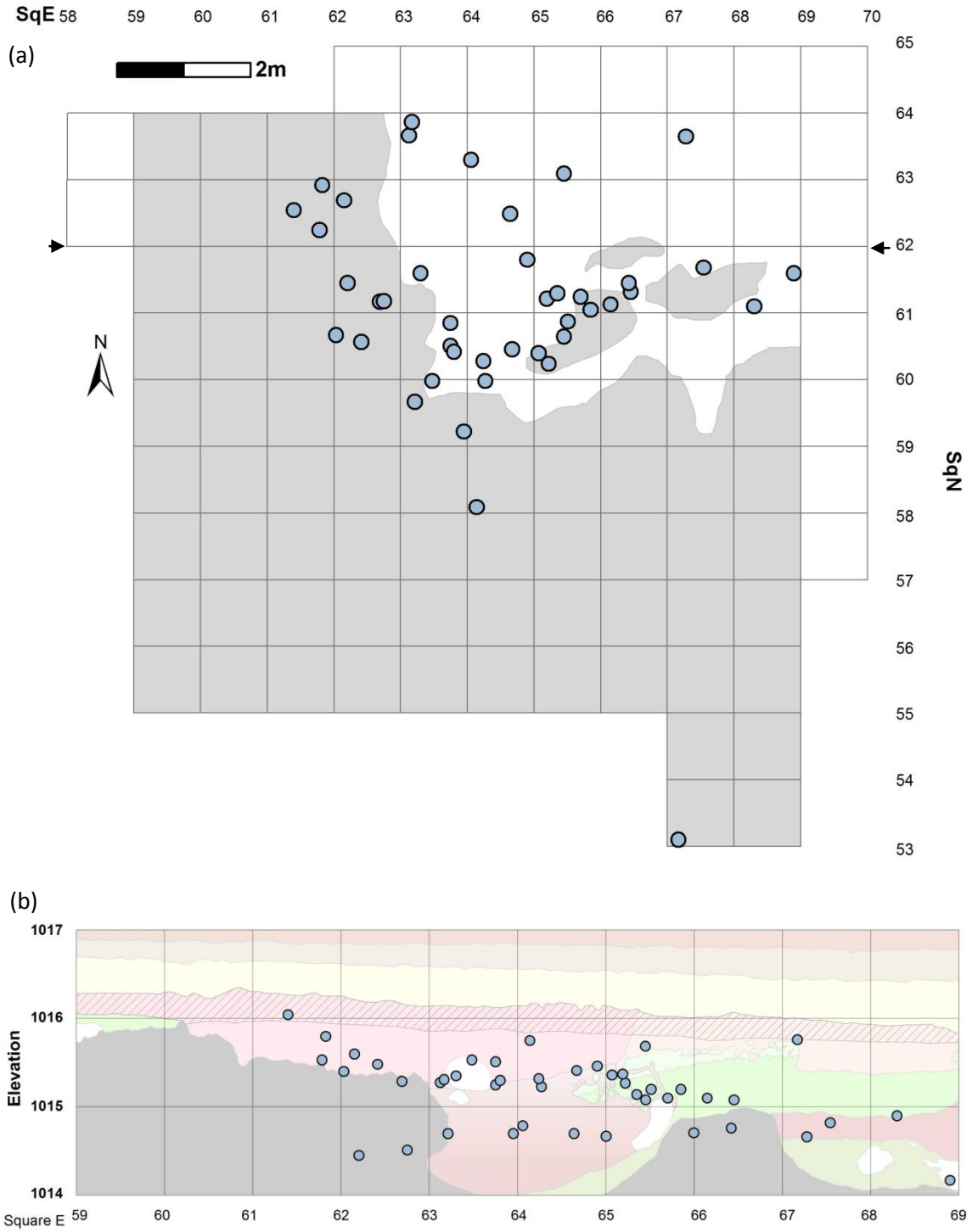
Figure 2.11. Distribution of bones exhibiting rodent gnaw marks (*n*=44) in B1 strata of Block 2 in plan (a) and East-West profile (b). One square = 1 m². The arrows in (a) indicate the location of the stratigraphic profile used as a backdrop in (b).
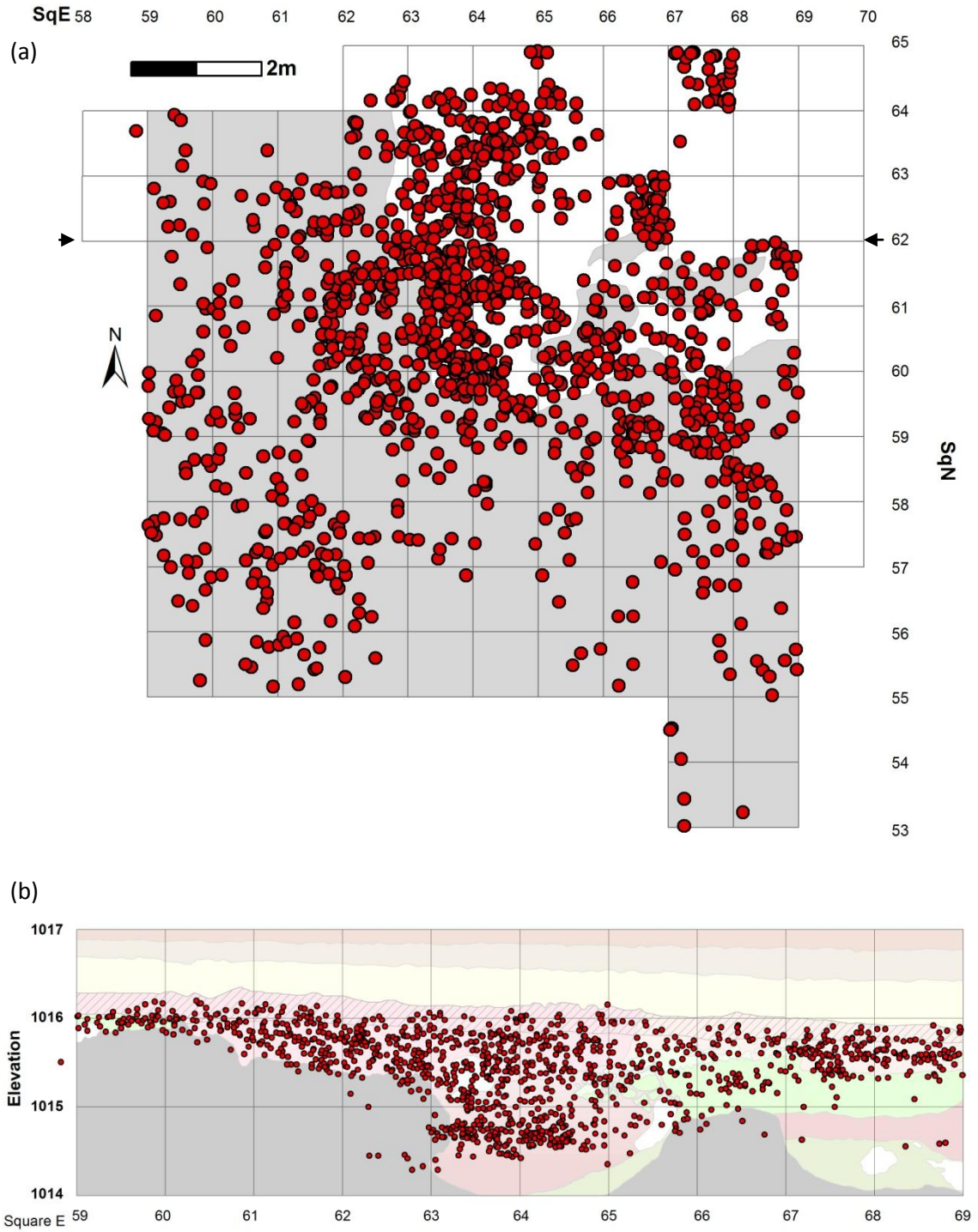
Figure 2.12. Distribution of all stones (*n*=1327) in B1 strata of Block 2 in plan (a) and East-West profile (b). One square = 1 m^2. The arrows in (a) indicate the location of the stratigraphic profile used as a backdrop in (b).
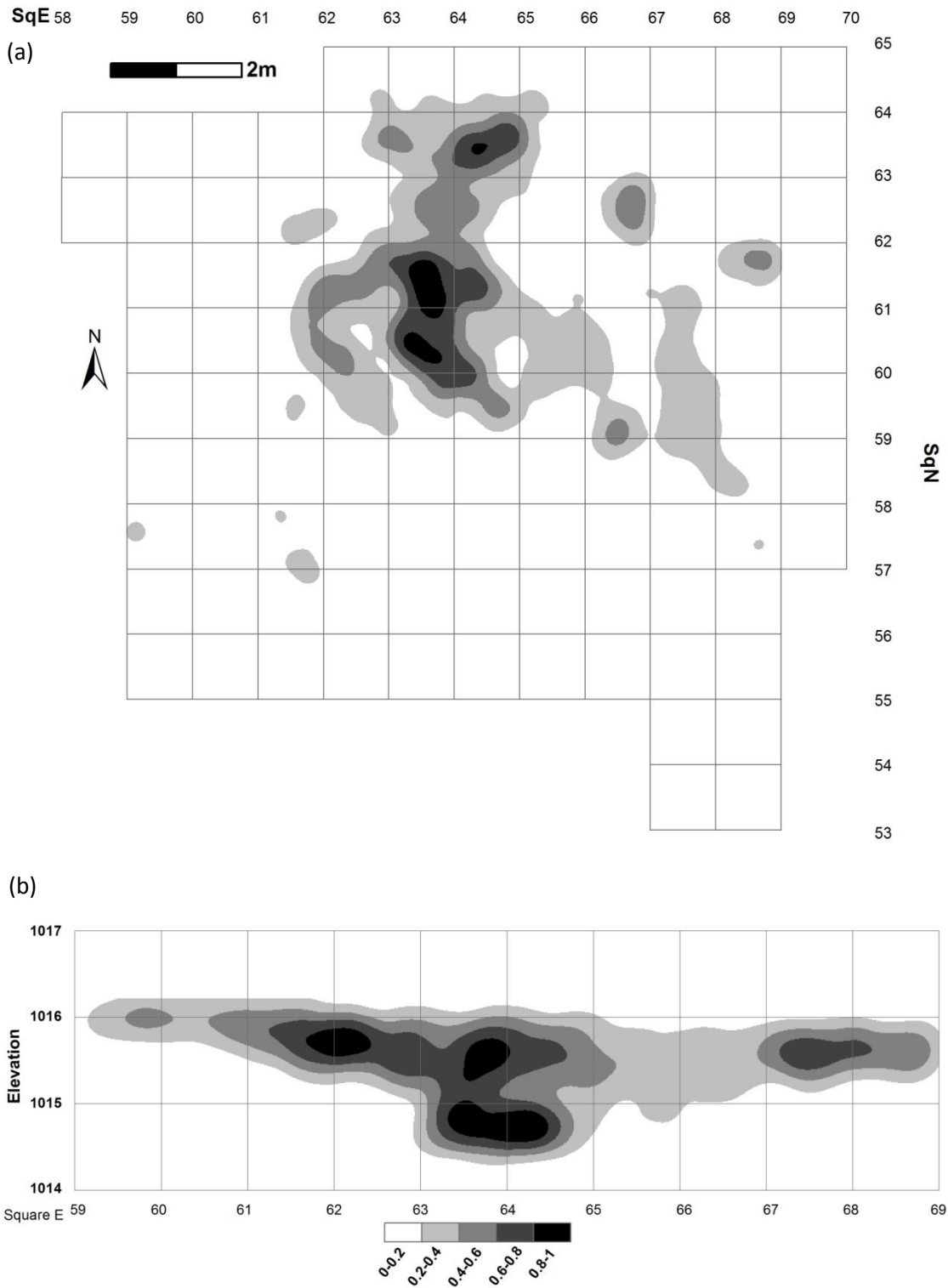
Figure 2.13. Kernel densities of all stones (*n*=1327) in B1 strata of Block 2 in plan (a) and East-West profile (b). One square = 1 m^2.
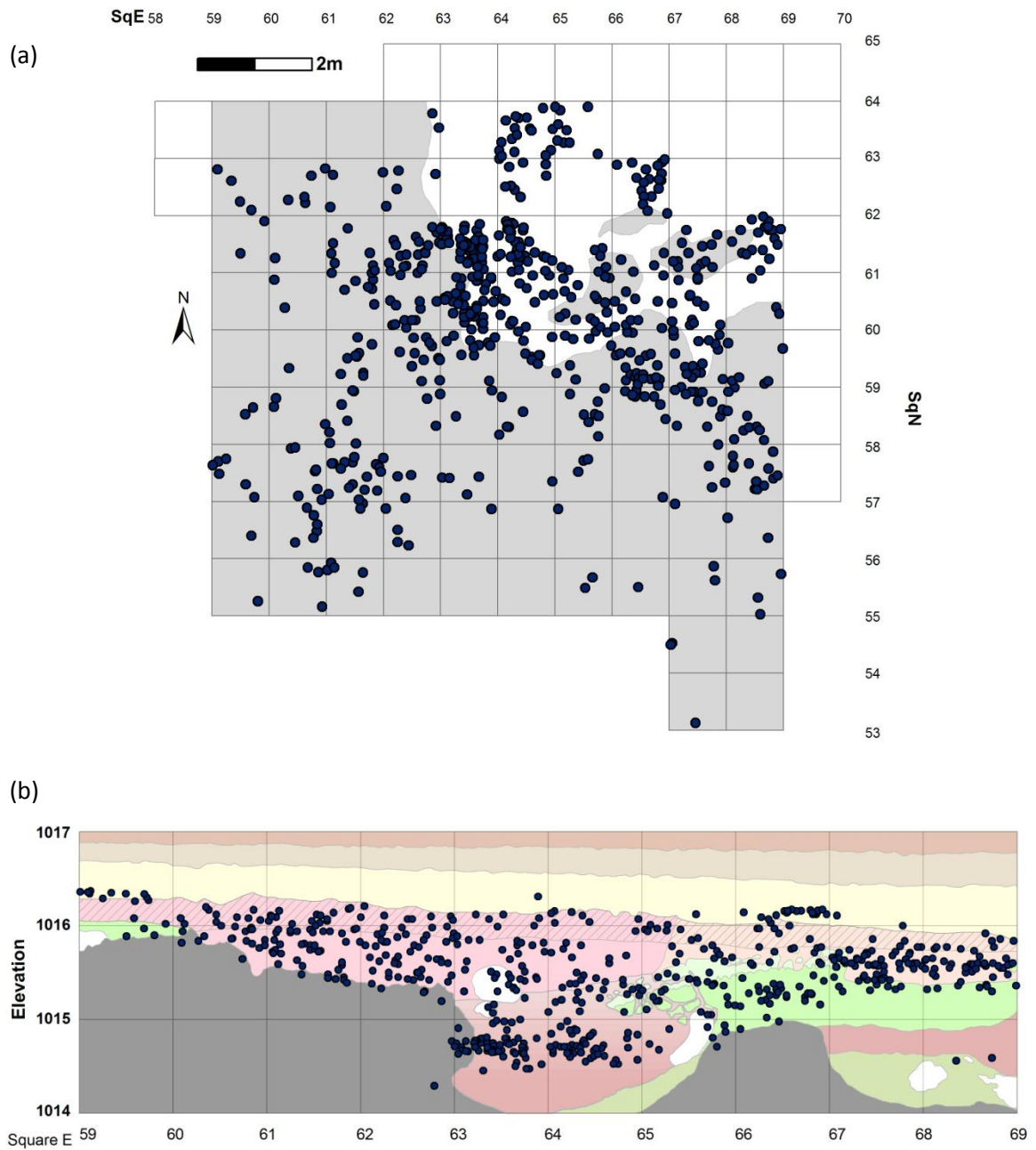
Figure 2.14. Distribution of cobbles (*n*=611) in B1 strata of Block 2 in plan (a) and East-West profile (b). One square = 1 m^2.
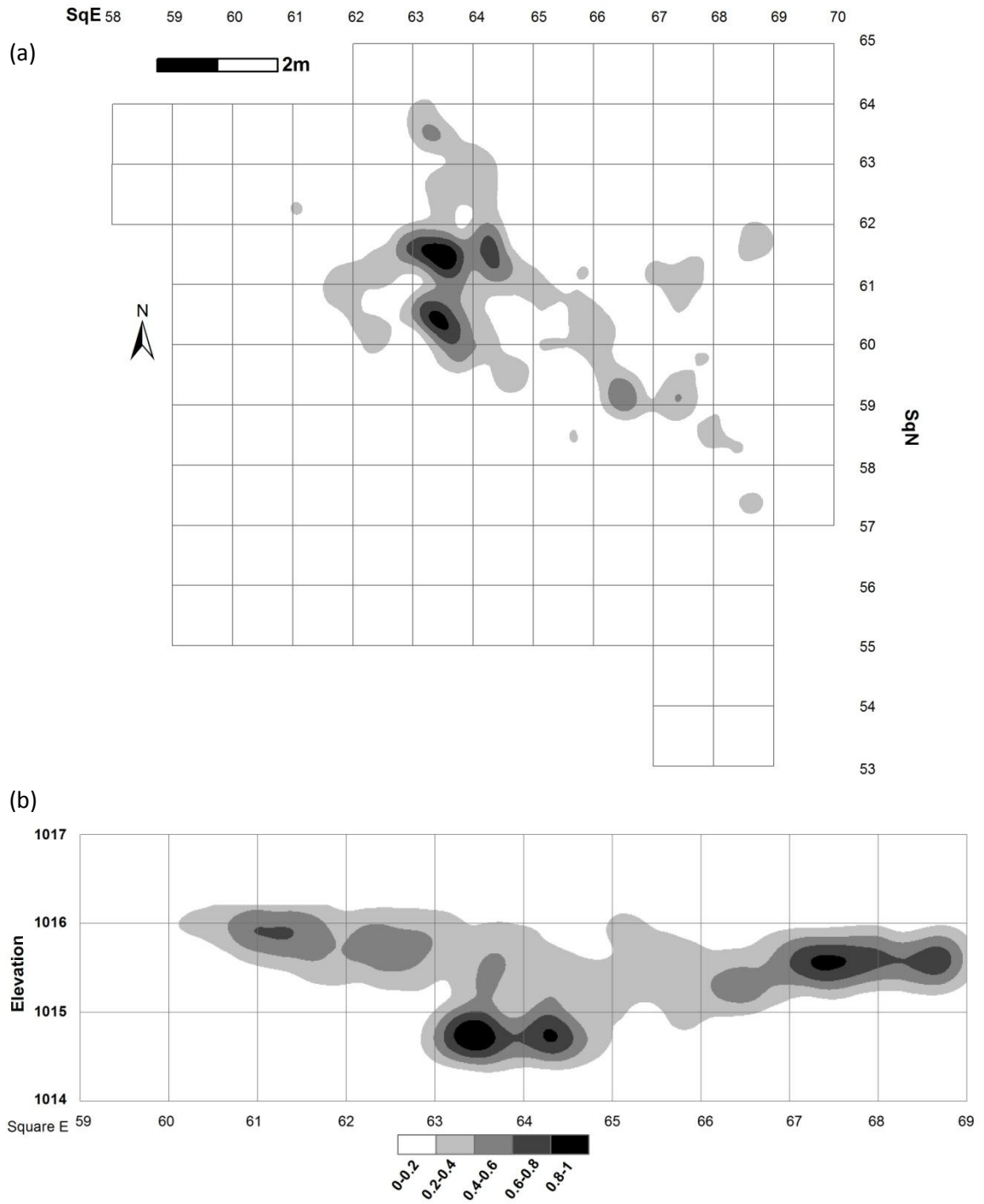
Figure 2.15. Kernel densities of cobbles (*n*=611) in B1 strata of Block 2 in plan (a) and East-West profile (b). One square = 1 m^2.
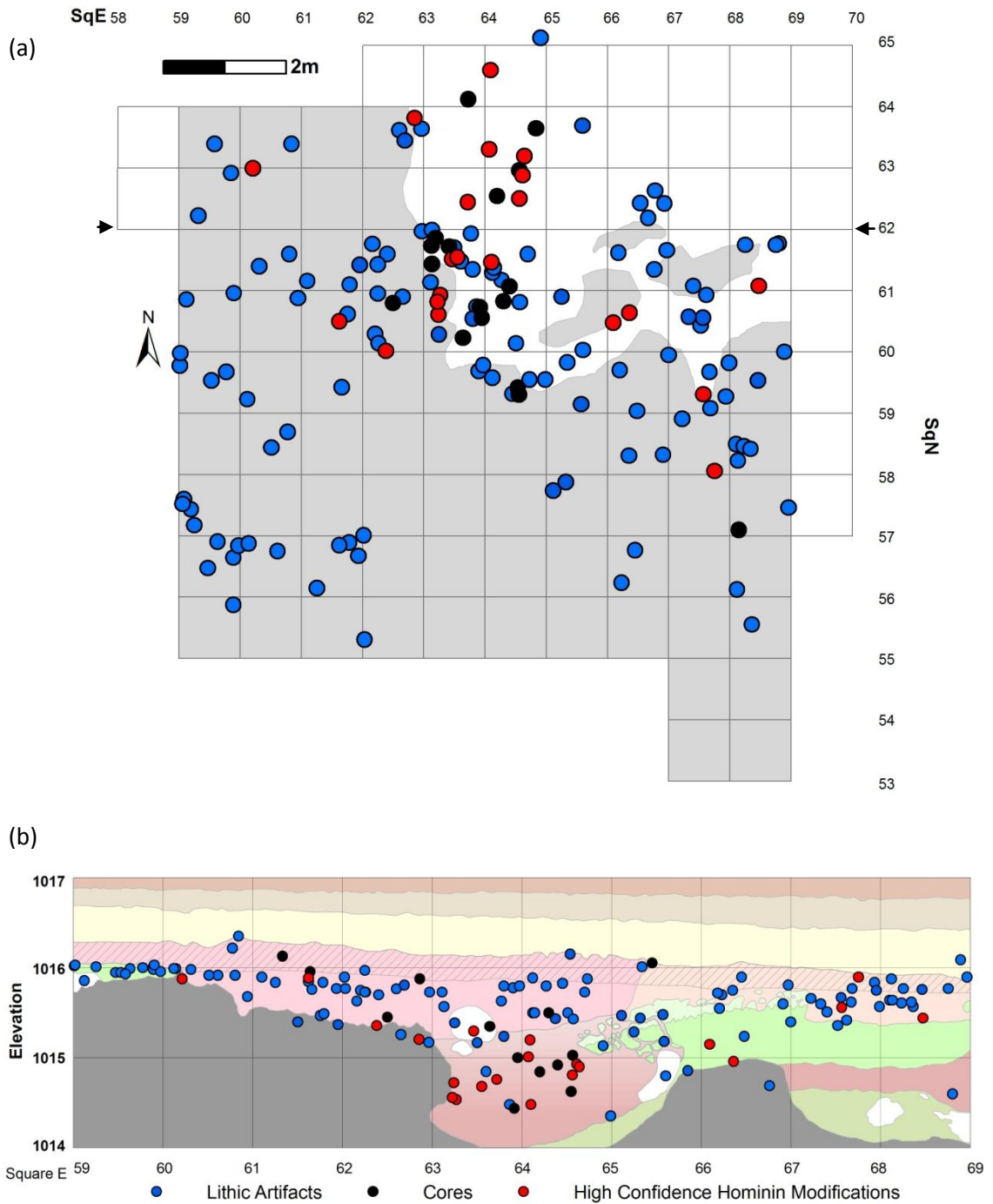
Figure 2.16. Distributions of hominin modified bones (High confidence tool marks and broken bones: *n*=21), lithic artifacts (*n*=111), and cores (*n*=13) in B1 strata of Block 2 in plan (a) and East-West profile (b). One square = 1 m². The arrows in (a) indicate the location of the stratigraphic profile used as a backdrop in (b).
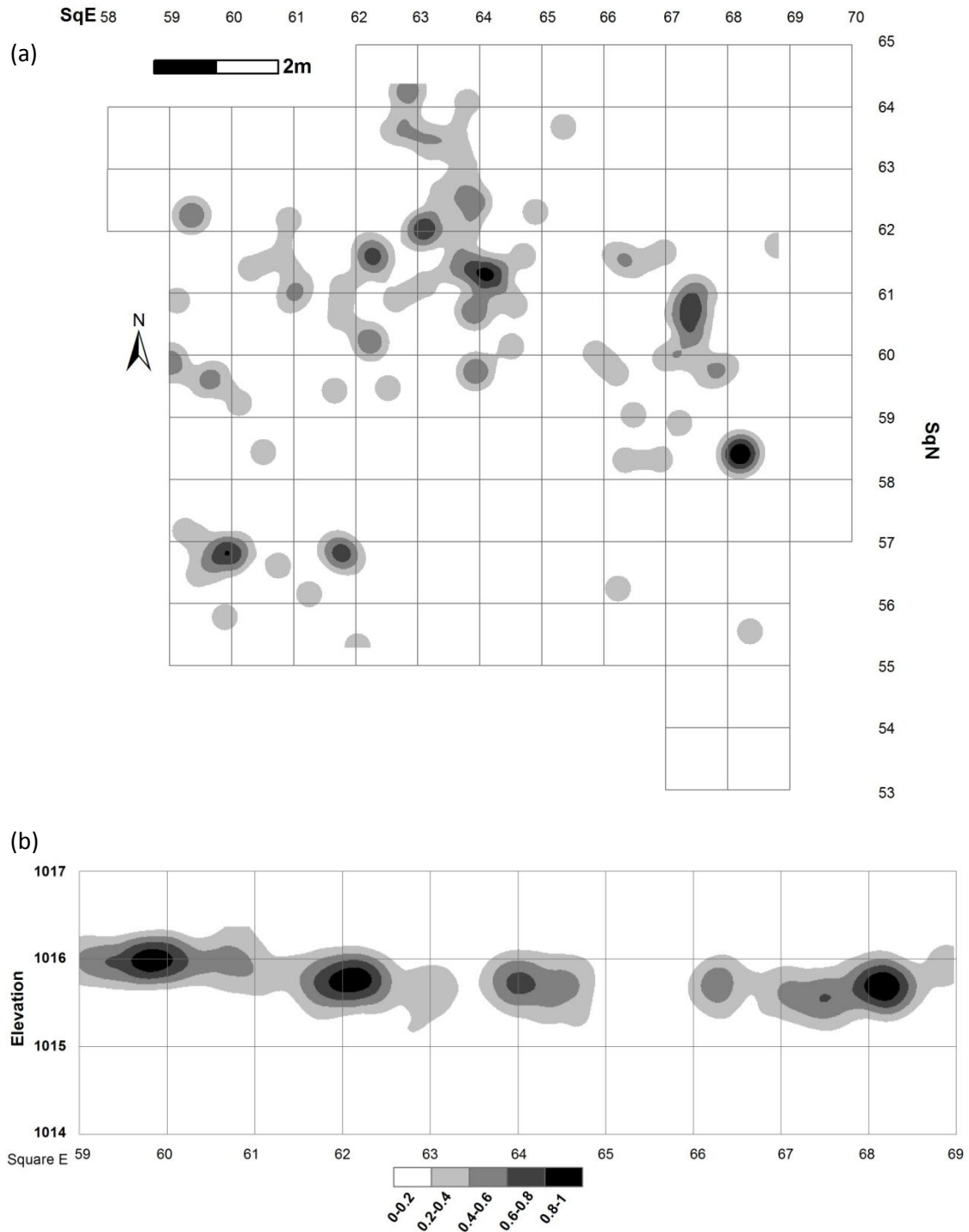
Figure 2.17. Kernel densities of lithic artifacts (*n*=111) in B1strata of Block 2 in plan (a) and East-West profile (b). One square = 1 m^2.

	B1		B1z		B1x		B1y	
	n	*%*	*n*	*%*	*n*	*%*	*n*	*%*
Cobbles	463	58.46%	21	42.00%	37	57.81%	90	69.23%
Lithic artifacts	97	12.24%	6	12.00%	4	6.25%	4	3.08%
Cores	6	0.76%	0	0.00%	3	4.69%	4	3.08%
Debitage	226	28.54%	23	46.00%	20	31.25%	32	24.62%
Total	792	100.00%	50	100.00%	64	100.00%	130	100.00%

Table 2.1: Restricted frequencies of different broad categories of stones in each B1 stratum. Categories are based on initial attributions by Medea Nioradze. Lithic artifacts include those identified as flakes and "stone tools." Debitage refers to debris created during lithic artifact production.

ABRIDGING CHAPTER FOR PAPER 1, 2, AND 3

Papers 1 and 2 are essential for understanding the depositional context of the stones and faunal material at Dmanisi. They both contribute evidence for the interpretations of site formation processes that accumulated the stones and faunal material, with a focus on the hominin bearing deposits.

Paper 1 tests previous interpretations about the role of abiotic site formation processes and supports the hypothesis that fluvial and colluvial transport played little part in the deposition of stones and faunal material in the pipe/gully fill strata, B1, at Dmanisi. By presenting these data for the first time from Dmanisi, we are able to compare our interpretations with other Paleolithic sites.

Paper 2 analyzes the spatial patterning of these pipe/gully fill strata in order to locate specific agent specific site formation. Differential distributions of stones and faunal material are apparent between the strata largely unaffected by basalt, B1 and B1z, and the strata enclosed by basalt and pipe/gully formations, B1x and B1y. More evidence for denning activities are present in B1x and B1y than the other layers and B1x has a concentration of coprolites located away from the primary concentrations of bone, which could be a latrine. Carnivores likely accumulated much of the faunal material in these lower elevations due to the protection offered by the basalt formations, with hominins playing a more marginal role.

Paper 3 offers another potential avenue for testing hominin and carnivore involvement in the modification of faunal material from marrow acquisition. Many of the long bone fragments at Dmanisi show fresh breaks but no associated surface

modifications that could be attributed to the agent that broke the bone. We aim to build on previously published studies on fracture angles and offer a new analytical methodology for examining these differences.

Although various forms of bone breakage analyses have been around for decades (e.g. Dart, 1957; Sadek-Kooros, 1972; Brain, 1978, 1981; Morlan, 1980; Binford, 1981; Shipman, 1981; Haynes, 1983; Johnson, 1985; Bonnichsen, 1989; Villa and Mahieu, 1991; Lyman, 1994; Outram, 1998, 2001), only recently have archaeologists began to use fracture angle measurements on long bone shaft fragments to examine the differences between carnivore and hammerstone created assemblages (Alcántara-García et al., 2006; de Juana and Domínguez-Rodrigo, 2011). The latter studies test hypotheses based on the assumption that the different agents of breakage use different modes of breakage: Humans swinging hammerstones to break bones is described as dynamic loading, where a sudden impact sends force throughout the bone instantaneously, whereas carnivores, such as hyenas, break bones by constantly applying more and more pressure until the bones cracks, which is called static loading. By performing controlled experiments, archaeologists can test whether these different modes of breakage create patterns in the resulting fracture angles, in turn creating analogues to compare to archaeological assemblages.

Alcántara-García et al. (2006) found that hammerstone broken bones resulted in fracture angle means further from 90° than those broken by carnivores. De Juana and Domínguez-Rodrigo (2011), however, found that their hammerstone created assemblage on horse bones resulted in fracture angles similar to the static loading assemblage from Alcántara-García et al. (2006). Other analyses on archaeological sites (e.g. Pickering et

al., 2005; Domínguez-Rodrigo and Barba, 2006) have used the results from Alcántara-García et al. (2006) for interpreting their breakage patterns. This is problematic in light of the study by de Juana and Domínguez-Rodrigo (2011), and it brings up more questions about how well we actually understand bone breakage dynamics. Do different taxa have varying bone structures that affect the resulting fracture angles? Does cortical bone thickness and overall bone morphology play a major role in force propagation, which in turn affects fracture angles? Are different fracture patterns apparent for different skeletal elements? Do adult and juvenile bones result in assemblages with similar fracture angle means?

In the third paper, we address the last two questions using the results from a controlled breakage experiment. We introduce a large experimental dataset from a new species/size class of animal that has yet to be analyzed: size class 3 Rocky Mountain elk. First we test the reliability of goniometer measurements by assessing inter- and intra-observer error. We then test different variables that could affect our dataset, which include age of the individual, skeletal element, and whether the bone frozen prior to breakage. We also compare preliminary data for bones broken by hammerstones and by hyenas to see if the different agents of breakage affect the outcomes. Understanding how these variables affect the resulting fracture angles is paramount for understanding bone breakage mechanics.

The co-athors contributed a great deal to the design and implementation of the experiment and to writing and revisions of the manuscript. Martha Tappen designed the research and methodology. Katrina Yezzi-Woodley led the hyena breakage portion of the experiment and assisted with statistics and R code.

PAPER 3:

New analytical methodology for comparing bone fracture angles: A controlled study of hammerstone and hyena (*Crocuta crocuta*) long bone breakage

SUMMARY

The accurate interpretation of the cause and timing of bones broken in the past and recovered in paleoanthropological contexts is an essential aspect of attributing hominin or carnivore agency. Yet many of the variables used in the interpretation of bone breakage have not been systematically explored. Here, we introduce a new analytical methodology for comparing fracture angles the using absolute values of the fracture angle distance from 90°. We control for variables not systematically explored in other studies, such as the influence of skeletal element/ limb portion and skeletal age. We also present a comparison and analysis of experimentally produced assemblages of femora broken by humans (hammerstone percussion) and spotted hyena (*Crocuta crocuta*).

We show that skeletal elements affect fracture angles, and the proper identifications of bone fragments as upper (humerus, femur), middle (radius, tibia), or lower limb (metapodia) are required to compare fracture angles. Research on fracture angles should consider comparing breaks by limb portion as well as breakage plane for a thorough analysis. For femora, carnivore created fracture angles tend to be more oblique at the assemblage level than those created by hammerstones.

1-INTRODUCTION

Both humans and carnivores exploit marrow resources by cracking open the long bones of hunted or scavenged animal remains. Fossil and archaeological bones are often found broken, and, if we can correctly infer the timing and cause of the breakage, we are in a much better position to interpret hominin meat and marrow exploitation strategies, hominin-carnivore interactions, agent(s) of bone accumulation, and general site formation issues. Within archaeological contexts, it is generally assumed that the most common agents/effectors of post-mortem fresh bone breakage are hominin tool users and carnivore teeth.

Although there have been many studies of bone breakage attempting to attribute breakage form to particular causal agents and effectors, equifinality remains a problem (Brain 1978, 1981; Dart 1957; Haynes 1983; Johnson 1985; Lyman 1994; Morlan 1980; Outram 1998, 2001; Sadek-Kooros 1972; Shipman 1981; Villa and Mahieu 1991). This equifinality concern is paralleled in many taphonomic issues, such as in cut mark studies (e.g. Thompson et al. 2015) and with mortality curves (e.g. Stiner 1994). For bone breakage, signatures of human intentional breakage once included spiral fractures (Dart 1957, 1959; Sadek-Kooros 1972; Bonnichsen 1989), but we now know that effectors other than twisting between the hands – such as carnivore teeth – can result in spiral fractures, (e.g. Binford 1981; Brain 1981; Haynes 1983; Myers et al. 1980). Peeling, most commonly on ribs, may indicate human breakage (White 1992; Pickering et al. 2013), but can also be made by carnivores (Arilla et al., 2014; Pickering et al. 2013). Notched breaks with broad arcuate shapes and high release angles have also been suggested to differentiate hammerstone from carnivore breaks, but there is a large overlap in shape and

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angle (Capaldo and Blumenschine 1994; Soderberg and Tappen under review). Some types of breaks are often quite good for identifying carnivore damage, like "crenulated," or "ragged edge," breaks and scooped out articular ends (e.g. Maguire et al. 1980; Haynes 1983).

The most common methods in breakage studies use categorical variables (Outram 1998, 2001; Shipman 1981; Villa and Mahieu 1991; White 1992). These systems are good at distinguishing fresh from very dry bone and post-fossilization breaks, but still cannot fully separate the agents of fresh bone breakage. In practice, agents of breakage are often identified using surface modifications such as percussion marks, tooth marks, and trampling marks adjacent to the break and not the break morphology per se (e.g. Galan et al. 2009). However, surface marks on excavated bones are often obscured by etching, exfoliation, abrasion, or matrix, and many bone fragments, even if well preserved, can be entirely devoid of surface marks.

Previous studies have suggested that carnivore tooth loading is slower and more akin to static loading, resulting in more right-angled fractures than the dynamic loading of hammerstone, which is more rapid and leads to more oblique fracture angles (Alcántara-García et al. 2006; Bunn 1983; Capaldo and Blumenschine 1994). Alcántara-García et al. (2006) quantified fracture angles of their experimentally broken bones and found that "static" loading produced fracture angles between 80˚ and 110˚, while "dynamic" loading resulted in more obtuse (>110˚) or acute (<80˚) angles. The resulting fracture angles from Alcántara-García et al.'s (2006) experiments seemed to be congruent with those observed in notches by Capaldo and Blumenschine (1994), where carnivore-made notches possessed release angles closer to 90˚ than those made by hammerstones.

Pickering et al. (2005) and Domínguez-Rodrigo and Barba (2006) followed Alcántara-García et al.'s (2006) quantitative methods on long bone shaft fragments and compared their results to interpret bone breakage from Swartkrans and Olduvai, respectively.

More recently, however, de Juana and Domínguez-Rodrigo (2011) produced an experimental assemblage of equid bones broken by hammerstones and observed opposite trends to those seen in the similarly sized cow bones examined by Alcántara-García et al. (2006), i.e. hammerstone breaks on equid bones generated more oblique fracture angles than hammerstone broken bovid bones and were more similar to the carnivore broken sample. Thus, the complexities of characterizing bone breakage remain apparent, most likely due a large number of variables, such as the non-homogeneity of bone; intrinsic variation of shape, size, and cortical bone thickness for each skeletal element, including variation during ontogeny; and the size of the effector and the angle and rapidity of loading.

It is within this epistemological framework that two important questions emerge: Do fracture angle measurements really help determine the agents that break bone, or is there too much overlap? What other factors besides the breakage agent significantly affect the results at the assemblage level? The latter question arises from the conflicting results of previous studies (Alcántara-García et al. 2006; de Juana and Domínguez-Rodrigo 2011) and our own general observations of breakage. Specifically, in this study we wanted to determine whether particular skeletal elements tended to break differently. If, for example, humeri and tibiae typically break at different angles, then assemblages with different abundances of these skeletal elements could be misinterpreted by researchers. Therefore, we conducted a controlled study of experimental breakage using

elk bones that controls for variables never before systematically examined, such as the skeletal elements themselves (e.g. humerus vs. tibia). We focus on assemblage-level comparisons of fracture angles from the resulting long bone fragments measured with goniometers. We were also concerned about the precision and accuracy of our goniometer measurements, so we had multiple researchers take repeated measurements. We controlled for various marrow acquisition strategies, the skeletal age of the individual, the classification of the break plane, the size of the break, and the freshness of the bone. Our new analytical method reveals necessary stratifications of the breakage data for effective comparisons at the assemblage level.

2-SAMPLE AND METHODS

2.1. *Sample*

We conducted bone breakage experiments using two different methods: Breaking bones with a hammerstone on an anvil and feeding bones to a spotted hyena. To keep body size constant, we used bones only from the carcasses of farm-raised, Rocky Mountain elk (*Cervus canadensis nelsoni* [~500-1000 lbs; ~225-450 kg]), a size class 3 mammal (see Brain 1981 and Bunn 1982). The experimental hammerstone sample consists of 45 long bones with 729 measureable breaks on 264 fragments and the hyena-broken sample consists of 11 elk femora with 107 measureable breaks on 56 measured fragments (Table 3.1). For the hammerstone experiment, University of Minnesota students disarticulated and filleted long bones from two whole elk (=15 long bones) using stone tools. We also obtained 30 defleshed individual long bones from the same elk farm.

The individual long bones had been filleted by the farmer with metal implements and then frozen. Prior to the breakage experiment, all of the bones had been defleshed, but the periosteum remained.

Students broke all of the long bones along the diaphysis with the same hammerstone on a stone anvil. The anvil, composed of a coarse grained gabbro, weighs 11.2 kg with a greatest dimension of 271 mm. The hammerstone is a finer grained gabbro than the anvil and weighs 1.3 kg with a greatest dimension of 110 mm. We broke the bones from the whole individuals within 5 hours of death, while the other 30 bones had been frozen for an unknown length of time, but thawed for over 24 hours prior to breaking. The primary goal during the hammerstone breakage experiment was to access the marrow cavity as efficiently as possible. The most stable position of the bones on the anvil varied from element to element, though it usually proved to be the flattest surface of the long bone (e.g. either the medial or lateral shaft for metapodia).

The hyena-broken bone sample consists of eleven disarticulated, partially defleshed elk femora that were fed to an adult male spotted hyena (*Crocuta crocuta*) at the Milwaukee County Zoo. Like the hammerstone broken bones, these long bones were defleshed, but the periosteum remained. They had been previously frozen for an unknown length of time, but were thawed prior to being fed to the hyena. Due to concerns that the hyena would consume the entire bone leaving no remnant fragments for these analyses, ten bones were left with the hyena for less than 15 minutes. One bone, however, was left with the hyena to see what might happen. The hyena almost completely destroyed the bone, but lost interest after 30 minutes, leaving only two measurable fragments. Although zoo studies may not reflect the degree of fragmentation produced in varying contexts in

the wild (Gidna et al 2013; Pobiner 2007; Sala et al. 2014), they do result in assemblage breakage by the effector of interest, since the masticatory apparatus and its function remains the same. Thus, zoo studies should produce an array of fracture angles of some use in approximating the population of possible carnivore-produced angles. Since we had fewer opportunities for hyena bone breakage, we kept the skeletal element constant (femur), but we are currently continuing these experiments with other skeletal elements.

After breakage and collection, we stored all of the bones in a freezer until processing. After thawing, we gently boiled the bones for several hours, after which we removed the remaining adhering tissue and tendons. Next, we simmered the bones for several more hours and, after a final brief cleaning and rinsing, air dried them on tables in the lab.

2.2. *Fracture angle measurements*

We examined the bone fragments and classified breaks as oblique, longitudinal, or transverse according to fracture plane relative to the long axis of the bone (Figure 3.1; e.g. Villa and Mahieu 1991; Pickering et al. 2005).

Oblique breaks can be helical or straight, but we follow the break plane classification in order to compare our results with previous quantitative work on long bone shaft fragments. In addition, we found than many fragments containing only small portions of breaks were indeed continuations of helical fractures, thus using breaks that were helical would bias our sample towards larger breaks. We measured breaks longer than 2 cm on fragments larger than 4 cm. Our measurements expand on the previous

protocol set forth by Alcántara-García et al. (2006), who measured breaks larger than 4 cm, to include smaller fractures 2 cm and above. Measurements were made at the center of the break using a goniometer held between the periosteal and break edge surfaces. Of course, breaks can vary greatly in fracture angle along their course (e.g. Johnson 1985) and our approach reduces this variation to a single point. But by using the center of the break we aim to evaluate if this easily replicable and simple procedure reveals patterns at the assemblage level as suggested by previous researchers. We only measured bone fractures on the shafts of long bones. Thus the epiphyseal fragments measured had shaft portions preserved.

We did not study fracture planes with notches (see Capaldo and Blumenschine 1994; Soderberg et al. in prep). Some angles were not physically measurable, such as bone fragments with >50% but <100% circumference remaining (see Bunn 1989) and with highly acute fracture angles because the goniometer could not touch both the periosteal surface and the break surface simultaneously (*n*=27). We also did not measure breaks with hinge fractures because the topography of the fracture surface and angle vary widely at the same location. Each of the four observers measured each angle three times with a goniometer.

Measurements should be accurate and reliable and the process should be efficient and economical. It is important to control for intra- and inter-observer error so we can better understand the relative impact of measurement errors while using goniometers. Repeated measures of the same fracture angles inform on the replicability of the experiment, both between and among observers. The morphology of the bone fragment, as well as convexities and concavities of the break surface, can sometimes make

measurements difficult to take, leading to slight variations at the specimen level in some cases, but negligibly affecting the results at the assemblage level. Inter- and intra-observer tests reported below show that the measurement errors are not significant and help to alleviate concerns regarding goniometer inaccuracies and inconsistency.

2.3. *Statistical tests*

We observed that it was much easier to be consistent when measuring a right angle than when measuring a highly acute or obtuse angle. Generally, the further the angle is from 90°, the more the goniometer measurements vary (Dibble and Bernard 1980). By recognizing that there is high variation in fracture angle measurements further from 90°, especially on highly acute angles, we can more accurately interpret our results. With this in mind, fracture angle measurements were divided based on whether they were acute or obtuse.

Permutation tests using *F* and *T* statistics are used for group and pairwise comparisons, respectively. Permutation tests are an effective way to compare different sets of data that do not conform to normal distributions. Essentially, permutation tests use the observed data to construct distribution curves based on a certain test statistic. Each permutation creates a distribution curve and all the resulting curves are compared to one another (in this case, 5000 times). The null hypothesis of a permutation test states that all permutations result in the same distribution curve. Thus, if datasets are statistically different, then there is a low probability that the permutations will generate similar distribution curves more than five percent of the time.

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For inter-observer tests R.C. and three undergraduate students measured 146 breaks three times and all of the measurements are compared to each other using permutation tests on both the acute and obtuse measurements. Additionally, a larger sample based on R.C.'s measurements ($n=441$) is assessed for intra-observer error using the same methods. The null hypothesis for each test is that the groups represent samples from the same population and there will be no statistical difference between groups ($p>0.05$).

Comparisons within the hammerstone assemblage and between hyena and hammerstone created assemblages of femora are also separated into acute and obtuse angles. For significant groupwise permutation tests, Tukey Honest Significant Difference (HSD) tests were subsequently run for family comparisons on skeletal elements and limb portions (confidence level=0.95). As with the previous tests, the null hypothesis is that each group represents a sample from the same population and p is expected to be >0.05. Tests for effect size (Cohen's d) are also run for each pairwise comparison within the hammerstone assemblage. We ran all statistical tests in R (v. 3.0.2). Graphs and tables were generated in Microsoft Excel.

3-RESULTS

3.1. *Intra- and inter-observer error*

We tested intra-observer error by examining differences among the three measurements by each researcher on each fracture angle, using only oblique breaks for these comparisons. For the intra-observer error of the larger sample (n=441), the

permutation tests showed that there is no statistical difference between any of the sets of measurements regardless of angle type (acute: $p=0.590$; obtuse: $p=0.877$). These results suggest that measuring each angle more than once is redundant and unnecessary in order to attain consistent results at the assemblage level.

For inter-observer error, the permutation tests between observers resulted in no statistical difference between any of the researchers' data regardless of angle type (acute: $p=0.943$; obtuse: $p=0.977$). Therefore, due to statistically similar results and a larger sample size, only R.C.'s measurements are used for the assemblage comparisons.

3.2. *Fracture angle comparison*

Fracture angles were tested against one another to see if there were differences in how far acute and obtuse angles averaged from 90. In order to compare these, we calculated the absolute value of fracture angles from 90°, and then ran pairwise permutation tests between acute and obtuse fracture angle on oblique and longitudinal breaks. We found statistically significant differences (oblique: $p=0.0004$; longitudinal: $p=0$) between each set, and will therefore examine acute and obtuse angles separately.

3.3. *Fracture plane comparison*

The hammerstone experiment resulted in 441 oblique, 265 longitudinal, and 23 transverse fracture planes greater than 2 cm (Table 3.2). Alcántara-García et al. (2006) found that transverse breaks were rare and the fracture angles had a high degree of

overlap between "dynamic" and "static" forces. In agreement with Alcántara-García et al. (2006) and Pickering et al. (2005), we focused our analysis on oblique and longitudinal breakage planes. The distribution of the measured fracture angles separated by breakage planes and the absolute distances of those fracture angles from 90° are shown in Figure 3.2 (Table 3.2).

A permutation test comparing means on fracture angles for the oblique and longitudinal break planes resulted in a significant difference for both acute and obtuse angles (acute: $p=0$; obtuse: $p=0$), which does not support the null hypothesis (Table 3.3). It does, however, support the notion that different break plane orientations yield different distances from 90° at the assemblage level; in this case the longitudinal breaks are closer to 90° than the oblique breaks. Therefore, as demonstrated by Alcántara-García et al. (2006) and Pickering et al. (2005), it is necessary to analyze each breakage plane category fracture angle assemblage separately. The analyses in the following five sections will look at oblique fracture planes only.

3.4. *Marrow acquisition strategy comparison*

We divided the assemblage to compare the different marrow acquisition strategies that were employed during the experimental hammerstone breakage. In the first year of the experiment, the goal was simply to access the marrow cavity in as few impacts as possible, which would limit physical exertion during breakage but could increase subsequent marrow extraction time. In subsequent experiments, a slightly different method was employed, similar to that of Bunn (1989), where the bone was struck at two

or more locations in order to access the entire length of the marrow cavity more effectively, but still with as few impacts as possible. The latter method may have had more exertion up front, but less work to fully extract the marrow supply. The permutation tests using the T-statistic resulted in no statistically significant difference between the two methods in obtuse and acute angles (Table 3.3). As a result, they are both included in the subsequent analysis of fracture angles.

3.5. *Bone freshness comparison*

Comparing fracture angle assemblages of the fresh bones and the once frozen bones informs us if prior freezing had confounding effects on the breakage dynamics (Outram 1998, 2001; Karr and Outram 2012a, 2012b). The permutation tests between the fracture angles of bones broken while fresh and the bones that were once frozen and then thawed before breakage resulted in no significant differences, thus supporting the null hypothesis (Table 3.3). Since freezing bones resulted in no differences for our study, we use fracture angles from both fresh and once frozen bone to increase our sample size.

3.6. *Long bone shaft fragments and epiphyseal fragments comparison*

Epiphyseal fragments have epiphyseal ends but also retain part of the diaphysis where break angles are measured They are less abundant than shaft fragments, but are typically more identifiable than long bone shaft fragments in archaeological assemblages.

Including the epiphyseal fragments in the analysis can increase the sample size of identifiable specimens to at least body size and many times to the precise taxon.

The permutation tests between long bone shaft fragments and epiphyseal fragments resulted in significant differences between the two assemblages for both acute and obtuse angles, rejecting the null hypothesis (Table 3.3). Here, we include both shaft fragments and those that have epiphyses in our analysis, for reasons which we will discuss below.

3.7. *Fused and unfused bone comparison*

Some of the bones used in our study have unfused epiphyses, including those from 18-month old females and individual bones that we estimate to be approximately the same age based on size and state of fusion. Skeletal structures change in size, shape, and mineralization during ontogeny, which can potentially change the fracture dynamics of the bone. However, we compared fragments from unfused and fused bones and the permutation tests resulted in no significant difference, which supports the null hypothesis that both the skeletally adult and juvenile bones produce similar fracture angle patterns (Table 3.3). This result affirms that skeletal age does not affect the breakage angles in any significant way in this study.

3.8. *Fracture length comparison*

We observed that smaller breaks (2-4 cm) shared many characteristic properties with breaks larger than 4 cm, so we include breaks with smaller dimensions than those analyzed by Alcántara-García et al. (2006). Our sample includes all measureable breaks >2 cm on fragments larger than 4 cm. We found no statistical difference between the two size classes using pairwise permutation tests, indicating that fracture angles for each size class had very similar distributions (Table 3.3). Therefore, all breaks larger than 2 cm are used in the following comparisons.

3.9. *Skeletal element comparisons*

Perhaps the most informative comparison is by skeletal element. Table 3.4 shows the sample size, mean, and the absolute value of fracture angles from 90° for acute and obtuse angles on both longitudinal and oblique breaks for each skeletal element and limb portion. Oblique breaks for each skeletal element were compared to all other oblique breaks through groupwise permutation tests in order to determine if there are differences between the skeletal elements. The test results for both acute and obtuse angles ($p=0$ for both tests) reject the null hypothesis that there are no differences between fracture angles of skeletal elements.

Since the permutation tests using the *F*-statistic determined that there is a statistically significant difference among skeletal elements, Tukey HSD tests were run for each pairwise comparison to locate the differences. The results of the Tukey HSD for acute and obtuse angles on oblique breaks show that there are significant differences between several sets samples (Table 3.5). Thus, the null hypothesis that all long bone

elements at the assemblage level will produce fracture angle means that are statistically indistinguishable is not supported. The histograms (Figure 3.3) show that the highest proportion of near right-angled breaks belongs to the metapodia, followed by the tibia and radius. The femur and humerus have generally more oblique fracture angles.

While identifying bones from fragmented assemblages, sometimes it is difficult to determine the exact limb element but one can often identify fragments to upper (humerus, femur), middle (radius, tibia), or lower (metacarpal, metatarsal) limb bones based on the morphology (Pickering et al. 2006). Permutation tests on fracture angles according to limb portion resulted in a significant difference for both acute and obtuse angles ($p=0$ for both tests), so further Tukey HSD tests were run. Based on the Tukey HSD test results, the fracture angles of upper limb bones (femur and humerus) are significantly different than the middle and lower limb bones (Table 3.5). The histogram shows a similar, more right-angled distribution for the middle and lower limb bones and a more oblique distribution for upper limb bones, which corroborates the Tukey HSD test results (Figure 3.4).

We also tested longitudinal fracture angles for each skeletal element to see if the pattern persisted. In contrast with the oblique fractures, permutation tests resulted in significant differences among the skeletal elements for longitudinal fractures for both acute and obtuse angles (acute: $p=0$; obtuse: $p=0.0018$). Since the permutation tests returned significant p-values, Tukey HSD tests were run. It is not surprising that there is less difference when comparing longitudinal break fracture angles in these elements, since longitudinal break fracture angles tend to be more right angled than fracture angles

from oblique breaks at the assemblage level, as demonstrated above. Some pairwise comparisons did, however, result in significant differences (Table 3.5).

Comparisons based on limb portions for the longitudinal breaks also show significant differences as seen in the oblique breaks and limb portion, though only for acute angles. The permutation tests between fracture angles by limb portion resulted in a significant difference for acute angles ($p=0$), but not of obtuse angles ($p=0.3636$). When looking at the pairwise comparisons on acute angles using the Tukey HSD tests, the upper limb bones are significantly different from the middle and lower limb bones. However, there is no significant difference between lower limb bones and the middle bones (Table 3.5). This suggests that, although longitudinal breaks generally have fracture angles closer to $90°$ than oblique breaks, upper limb bones still have more oblique fracture angles than middle and lower limb bones.

3.10. *Hammerstone and Carnivore fracture angle comparison*

The results of our hyena breakage experiment are based on a sample made up only of femora, and thus should be considered preliminary. Though we have only one element, we have similarly sized samples of measured breaks on femora for the hammerstone and hyena samples (Figure 3.5 and Table 3.3). The pairwise permutation tests between the oblique breaks of the two groups resulted in no significant difference between the two assemblages for the obtuse angles ($p= 0.131$), supporting the null hypothesis that both hyena and hammerstone breakage assemblages yield similar fracture

angle means. Acute angles, however, resulted in a significant difference ($p= 0.0288$), thus rejecting the null hypothesis.

Permutation tests comparing fracture angles on longitudinal breaks between these two groups resulted in no significant difference for both acute and obtuse angles (acute: $p=0.253$; obtuse: $p=0.083$). The means for each group are more similar, again affirming that longitudinal break fracture angles are probably less informative than oblique breaks (Table 3.3).

4-DISCUSSION

Our methodology explores bone fracture angles, one of many aspects of bone breakage that can be studied. The purpose is to scrutinize this aspect of breakage with variables that may influence them. Our work expands on the few explorations of this primary variable first quantified by Alcántara-García et al. (2006).

We found that smaller breaks (2-4 cm in length) are likely as informative as larger breaks (>4 cm) and can be included in analyses. As shown in Table 3.3, over half of our oblique break sample comes from breaks that are 2-4 cm, and there is no statistical difference between fracture angles on breaks less than 4 cm and those greater than 4 cm. Our observations of these breaks disagree with Alcántara-García et al. (2006) in the sense that many of these small breaks do represent an entire, unconstrained break surface, especially for oblique and transversely oriented breaks. Furthermore, only including break surfaces larger than 4 cm can lead to a potential bias towards longitudinal breaks, and may limit the number of usable breaks in size class 1-2 animals because their long

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bone shaft widths can be less than or close to 4 cm. As a consequence, oblique breaks

will be underrepresented, which is even true for our results with a larger size class (Table

3.3). In relation to this idea, helical fractures are easier to identify on larger breaks, and

continuations of these fractures may go unrecognized on smaller break surfaces. In

addition, helical fracture identification seems to be relatively subjective and no clear

definition encompasses all varieties of helical fractures. In an archaeological scenario,

this is problematic, since all ranges of breaks and fractures angles result from both hyena

and hammerstone breakage.

In addition to the inclusion of shorter break surfaces, we include fragments that

retain an epiphysis in our fracture angle analysis for a few reasons: 1) to increase sample

size and 2) we have located a potential measurement bias pertaining to epiphyseal

fragments. Generally, there is a very high success rate for identifying fragments retaining

whole or partial epiphyses to element, size class, and taxon. This inclusion becomes

extremely important, especially in light of the skeletal element and limb portion

comparisons.

The completeness of these specimens, however, is also a constraining factor on

data collection. For acute angles, fracture angle measurements on breaks connected to

epiphyseal fragments were closer to 90°. This is likely due to the difficulty in taking

goniometer measurements on these fragments, since the higher degree of circumference

remaining leaves more obstacles for measurement; thus, these breaks were not measured.

Also, we would expect that acute and obtuse averages to add up to 180°, since each

obtuse angle would have a corresponding acute angle. However, there is bias – the sum

of the acute and obtuse angles for epiphyseal fragments is 192.61°; the average for acute

angles is much higher than the expected, given the measured obtuse angle values. On the

other hand, highly obtuse angles are more frequent on epiphyseal fragments than long

bone shaft fragments likely because of the more durable nature of the epiphyses. Highly

obtuse fractures on long bone shaft fragments are probably more likely to break during

force propagation, leading to lower averages on long bone shaft fragments. These

interpretations are based on observations of our assemblage, but further analyses of these

factors must be considered.

When looking at the sum of the acute and obtuse angles for each variable (Table

3.3), all but one variable (long bone shaft fragments) have sums higher than 180°. Again,

this demonstrates a measurement bias against highly acute angles, likely resulting from

the morphology of the bone fragments and the constraints of the goniometer itself. This

bias would result in asymmetrical distance estimates from 90°. Surely, if humans or

carnivores are breaking bones, there should be a symmetrical distribution of fracture

angles above and below 90°, since each obtuse angle has an acute pair. Obviously, other

factors including very small fragments created and force propagation play a role in

deletion of measurable breaks, but this bias is an important notion to consider.

Our results support the notion that bones break differently based on their overall

shape and cortical bone thickness and density, which tend to increase as one moves

distally down the limb. Therefore, it is important to compare bones from the same limb

portions (upper, middle, lower limb), if not the specific element themselves. This can be

problematic for archaeological assemblages where the long bone shaft fragments are not

easily identifiable to element, but if they are identified to portion, the comparisons can be

made. This limb portion difference relates back to our initial question regarding what

other factors besides breakage agents affect the breakage dynamics. Given our results, perhaps the question can be approached through a discussion of bone structure itself and the factors that influence breakage dynamics.

Altogether, bone is hierarchically structured; it can be dense cortical bone, which can be primary lamellar bone or have various degrees of Haversian remodeling, or it can be trabecular bone, with struts occurring at various thicknesses and angles. At a finer scale, bone is composed of mineral crystals that are arranged along collagen fibers that run parallel to the longitudinal axis of long bones. This organization of collagen and mineral crystals is a critical factor affecting the strength and fracture of bone (Burr and Allen 2014; Ji and Gao 2004; N.C. Tappen 1969). For these reasons bone is anisotropic and viscoelastic. Viscoelasticity of protein in bone assists in the dissipation of fracture energy (Ji and Gao 2004). Bones are stronger under compressive strain than tensile or shear strain, and cracks and breakage may follow structures at various levels (Burr and Allen 2014; Symes et al. 2014). Thus, these structural properties of bone can provide predictive parameters for assessing how bone will fracture.

At the elemental level of bones' structural hierarchy, there is considerable morphological variability. Each element (femur, metatarsal, etc.) has its own unique shape and the thickness of the cortical bone varies across it. The size of the element and the thickness of the cortical bone vary allometrically across size classes. The stressed volume effect asserts that large volumes will fail faster than smaller volumes (Taylor and Kuiper 2001) so there is an interplay between mass and volume and the effect on stress resistance. Additionally, there is taxon specific aspect of variation related to bone thickness, shape, and quantity of marrow. As animals age, bone fusion states change and

mineralization accelerates, though we found that unfused bones of near adult-sized animals did not break at statistically different angles than the adult fused bones. These intrinsic factors affect how fresh bone will respond to localized force and how breaks will propagate.

There are also extrinsic factors that need to be considered, such as the source of the force and how it is exerted on the bone. There are several agents that can create the force necessary to break a bone, including hominins, carnivores, trampling by animals, etc. Not only can there be variability in the agents, but also in the effector employed by the agent (e.g. stone tool, dental arcade, or hoof). A jagged-edged chopper will make contact with the bone differently than a rounded hammerstone. The same can be said about the premolar versus the molar, the typical bite points for bone cracking hyenas versus bone crushing canids, respectively (Tseng et al. 2011; Werdelin 1989). Not only is effector morphology a consideration, but so is its size. Carnivore teeth are smaller than hammerstones and arranged in a linear fashion. Hammerstones and anvils also vary in size.

The magnitude and the angle of force can also affect how bone will break, whether oblique or perpendicular to the main axis of the bone. The location of the force, whether midshaft or closer to the proximal or distal end, will impact bone breakage patterns, though not significantly in our analysis of fracture angles. The rate of loading varies among agents. A hammerstone strikes the bone quickly from a back swing some distance from the bone, whereas a carnivore gnaws or bites down on the bone with supposedly a slower, more continuous pressure (referred to in some of the literature as dynamic or static, respectively) (Bunn 1989; Capaldo and Blumenschine 1994). The

number of times the bone is struck or bitten will also vary by individual agent and their situation.

The state of the bone at the time of breakage influences outcomes. If the bone is broken shortly after death, the break takes on characteristics of green bone fractures. As collagen decays and the bone and the mineralization process advances, the breaks become dry breaks. However, there are various stages that are not addressed by the dichotomy of "green" and "dry" break categories. After death, as the bone loses water and the organic material decays, the viscoelastic properties are lost. However, drying occurs over a continuum of time, resulting in a gradual transition from fresh to dry. The fracture characteristics of bones broken over longer periods of time since death change, and break surfaces become more often jagged, nearer to right angles, and have fewer curved fracture outlines over a duration of months (Symes et al. 2013; Wieberg and Wescott 2008). Our experimental bone fracture angles were indistinguishable even if the bone had been previously frozen and then thawed, so to detect this experimental history one would need to use other variables (Karr and Outram 2012a, 2012b).

Our results indicate that some variables quantifiably affect fracture angles. Specifically, the shape and size of different limb bones, along with cortical bone thickness, appear to affect the resulting fracture angles at the assemblage level. Furthermore, our data indicate that within the femora carnivore tooth and hand held hammerstone breakage create mixed assemblages of fracture angles, where all but one comparison were statistically indistinguishable.

5-CONCLUSIONS

We provide a new method for analyzing bone fracture angles using raw angles and the fracture angle distance from 90° at the level of the bone assemblage. We show that, in many cases, fracture angles are strongly affected by the skeletal element or limb portion from which the bone fragment originates. In some areas, our results agree with what other researchers have already postulated, i.e. oblique breaks should be compared to oblique breaks (Alcántara-García et al. 2006; de Juana and Domínguez-Rodrigo 2011; Pickering et al. 2005). However, contrary to the results from the breakage experiment from Alcántara-García et al. (2006), our results indicate that at the assemblage level for the femur, hyena created assemblages tend to have fracture angles further from 90° than those made by hammerstone (Figure 3.5). It is possible that some of these differences are due to different taxa used in the experiments, because Alcántara-García et al. (2006) used sheep, goat, pig, and cow bones while de Juana and Domínguez-Rodrigo (2011) used horses bones, and the latter study received similar results to our study. This may suggest that the idea that hammerstone breakage creates more oblique fracture angles than carnivores is incorrect. Of course, expanded experiments for all size classes could inform further on this topic.

In any case, the application of inferential statistics has revealed several interesting points.

(1)   Several variables do not impact fracture angles, therefore sampling does not need to be stratified based on these variables. This allows the inclusion of a broad sample of measureable fracture angles and mitigates potential sampling biases.

- Within the hammerstone sample, it did not matter whether the bones were struck in one location at the center of the shaft or at two or more locations along the shaft.

- The changes in the skeletal structure during the late stages of ontogeny have no bearing on fracture angles and adults and sub-adults can be analyzed together (near 1.5 years and older for elk).

- The inclusion of smaller fracture planes avoids bias due to exclusion of small taxa. Fracture length, whether greater than or less than 4 cm, did not show significant differences in fracture angle.

(2)   Break plane, skeletal element, and skeletal region does affect fracture angles and thus samples should be stratified according to these variables.

- The inclusion of epiphyseal fragments not only broadens the sample size, it allows for the analysis of specimens that are more likely to be identified to taxon. Measurement bias pertaining to goniometer methodology likely plays a role in the

differences in acute angled fractures, while fracture mechanics and size bias resulting from the durability of epiphyseal fragments could have played a role in the obtuse angled fractures. Further analyses on these ideas are necessary to fully rule out their utility.

- Fracture angles from oblique breakage planes are probably more informative for comparisons than are those of transverse and longitudinal breaks.

- Our results suggest that bones break differently based on their overall shape and cortical bone thickness and density intrinsic to different skeletal elements. Metapodia, tibiae, and radii are characterized by more right-angled fracture than humeri and femora.

- It may be best to compare bones based on whether they are from the upper, middle, or lower limb. This is helpful considering that oftentimes long bone shaft fragments can only be identified to that level.

Expanding the analysis of hyena breakage to include all skeletal elements should inform further on the usefulness of fracture angles for distinguishing between hyena and hammerstone breaks. Though there was one statistically significant difference between the fracture angles for the hyena versus hammerstone samples, mixed results encumber the predictive power of such tests. In most cases (3/4), hyena fracture angles on oblique breaks tend to be further from 90° (more acute or obtuse) than the hammerstone created

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fracture angles. Our limited sample of skeletal elements broken by hyenas supports the idea that assemblages created by hominins and hyenas certainly vary, but broadening the literature and experiments on this topic is necessary to understand the extent of the variation.

Ultimately, a combination of fracture angle, morphology, location, and surface modifications will be the best indicators for determining break cause, and teasing apart the influences on fracture angles is an important step in this direction. Locating the variables that influence breakage dynamics is paramount and this must be accomplished prior to confidently assessing the breakage agents involved. Based on our results here, where fracture angles are to be studied in archaeological contexts, researchers will have to identify shaft fragments to limb portion at the very least

.

Table 3.1: Experimental Hammerstone and Hyena-broken bones used in the study. The table shows the percentages of the fragments >4 cm with measured breaks >2 cm for the hammerstone and carnivore assemblages. Sample sizes refer to only measurable fragments and breaks. The Experimental Hyena-Broken Assemblage is exclusively on femora.

Experimental Hammerstone-Broken Assemblage					
Element	**_n_ Bones**	**% Bones**	**_n_ Fragments**	**% Fragments**	**_n_ Breaks**	**% Breaks**
Femur	11	17.46%	65	19.29%	193	20.55%
Humerus	9	14.29%	44	13.06%	136	14.48%
Tibia	11	17.46%	87	25.82%	225	23.96%
Radius	9	14.29%	45	13.35%	110	11.71%
Metacarpal	13	20.63%	47	13.95%	129	13.74%
Metatarsal	10	15.87%	49	14.54%	146	15.55%
Total	63	100%	337	100%	939	100%
Experimental Hyena-Broken Assemblage					
Femur	11		56		107	

Table 3.2: Results of Cohen's d and pairwise permutation tests for different variables in the hammerstone assemblage. The first column represents the first variable of the pairwise test and the second column is the second variable. Sample sizes are in parentheses. (df-degrees of freedom; Long-longitudinal breaks; HS 1-Bones struck in one location during breakage; HS 2-Bones struck in multiple locations during breakage; LBSF-Long bong shaft fragments; LBEF-Long bone epiphyseal fragments, <4 cm-Break lengths between 2 and 4 cm, >4 cm, Break lengths longer than 4 cm, HS-Obl-Oblique breaks from the femora of the hammerstone created assemblage, Hyena-Obl-Oblique breaks from the hyena created assemblage, HS-Long-Longitudinal breaks from the femora of the hammerstone created assemblage, Hyena-Long-Longitudinal breaks from the hyena created assemblage).

		Acute angle means		Obtuse angle means		Sum of obtuse and acute means		Cohen's d[1]		permutation test results	
Var1(n)	Var2(n)	Var1	Var2	Var1	Var2	ΣVar1	ΣVar1	acute	obtuse	acute p	obtuse p
Oblique(556)	Long(359)	68.17	74.19	114.5	109.16	182.67	183.35	0.401*	0.342*	**0**	**0**
HS 1(314)	HS 2(242)	69.2	67.55	114.5	114.5	183.7	182.05	0.102	-0.0002	0.166	0.999
Frozen(446)	Fresh(110)	68.19	68.09	114.43	114.8	182.62	182.89	-0.006	0.022	0.954	0.794
LBSF(382)	LBEF(174)	65.99	74.62	112.53	117.99	178.52	192.61	0.547**	0.33*	**0**	**0**
Fused(330)	Unfused(226)	68.98	66.87	113.62	115.7	182.6	182.57	0.13	-0.125	0.0852	0.0648
<4 cm(313)	>4 cm(243)	68.02	69.46	113.64	115.23	181.66	184.69	-0.088	-0.094	0.222	0.174
HS-Obl(116)	Hyena-Obl(76)	63.92	56.91	120.21	124.46	184.13	181.37	0.413*	-0.262*	**0.0288**	0.131
HS-Long(65)	Hyena-Long(31)	65.95	71.08	109.55	115.44	175.5	186.52	-0.34*	-0.445*	0.253	0.083

[1] - estimates of Cohen's d. Results without asterisks represent negligible size effects. * - Small size effects. ** - medium size effects.

Table 3.3: Sample sizes (*n*), means ($\bar{x}$), and absolute value of the distance from 90°
(abs(-90)) of acute and obtuse fracture angles on oblique and longitudinal breaks for
each skeletal element and limb portion.

| | Oblique Breaks | | | | | |
| | Acute | | | Obtuse | | |
Element	*n*	$\bar{x}$	Abs(-90)	*n*	$\bar{x}$	Abs(-90)
Femur	52	64.42	25.58	64	120.05	30.05
Humerus	37	61.75	28.25	49	115.84	25.84
Radius	31	69.39	20.61	37	114.43	24.43
Tibia	67	68.8	21.2	73	111.59	21.59
Metacarpal	37	75.41	14.59	29	110.69	20.69
Metatarsal	33	74.85	15.15	48	110.67	20.67
Upper	89	63.31	26.69	113	118.22	28.22
Middle	98	68.98	21.02	110	112.55	22.55
Lower	70	75.15	14.85	77	110.68	20.68

| | Longitudinal Breaks | | | | | |
| | Acute | | | Obtuse | | |
Element	*n*	$\bar{x}$	Abs(-90)	*n*	$\bar{x}$	Abs(-90)
Femur	27	65.96	24.04	38	109.9	19.9
Humerus	21	71.89	18.11	24	111.68	21.68
Radius	20	78.12	11.88	22	106.12	16.12
Tibia	41	76.08	13.92	38	109.46	19.46
Metacarpal	36	77.18	12.82	26	103.9	13.9
Metatarsal	26	76.82	13.18	40	111.18	21.18
Upper	48	68.56	21.44	62	110.16	20.16
Middle	61	76.75	13.25	60	107.89	17.89
Lower	62	77.03	12.97	66	108.31	18.31

Table 3.4: Results from Tukey HSD tests on the acute and obtuse fracture angles for oblique and longitudinal breaks on skeletal elements. The *p*-values are listed with those in bold being significant. Grayed out cells indicate the results for acute angles, and white cells are for obtuse angles.

Oblique Breaks

Element	Femur	Humerus	Tibia	Radius	Metacarpal	Metatarsal
Femur	-	0.820029	0.186295	0.255738	**0.0000001**	**0.0000172**
Humerus	0.187762	-	**0.009377**	**0.024043**	**0**	**0.0000003**
Tibia	**7.6E-06**	0.19017	-	0.999724	**0.0009841**	**0.0237966**
Radius	**0.039897**	0.97426	0.783215	-	**0.0254941**	0.1599645
Metacarpal	**0.001454**	0.418634	1	0.87412	-	0.9904143
Metatarsal	**4.8E-06**	**0.081331**	0.989467	0.510229	0.9984582	-

Longitudinal Breaks

Element	Femur	Humerus	Tibia	Radius	Metacarpal	Metatarsal
Femur	-	0.080847	**7E-07**	**1.1E-06**	**0.0000001**	**0.0000046**
Humerus	0.942059	-	0.240798	0.08433	0.099234	0.2366008
Tibia	0.999354	0.990521	-	0.989709	0.9940632	0.9998873
Radius	0.745725	0.310961	0.559583	-	0.9981228	0.9466548
Metacarpal	0.053149	**0.008851**	**0.021862**	0.832192	-	0.9998694
Metatarsal	0.939136	0.999998	0.992742	0.251768	**0.0030414**	-

Table 3.5: Results from Tukey HSD tests on the acute and obtuse fracture angles for oblique and longitudinal breaks on limb portions. The *p*-values are listed with those in bold being significant. Grayed out cells indicate the results for acute angles, and white cells are for obtuse angles. Numbers in italics represent Tukey HSD tests on non-significant permutation tests.

Oblique Breaks				Longitudinal Breaks			
Portion	Upper	Middle	Lower	Portion	Upper	Middle	Lower
Upper	-	**0.000416**	**0**	Upper	-	**1E-07**	**0**
Middle	**4.02E-05**	-	**1.23E-05**	Middle	*0.594471*	-	0.994124
Lower	**1.3E-06**	0.497652	-	Lower	*0.339661*	*0.918495*	-

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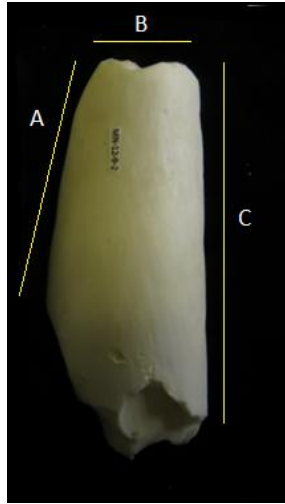
Figure 3.1. A labeled fragment illustrating the classifications of breakage planes relative to the long axis of the bone: A-Oblique; B-Transverse; C-Longitudinal. Photo taken by Sam Porter.
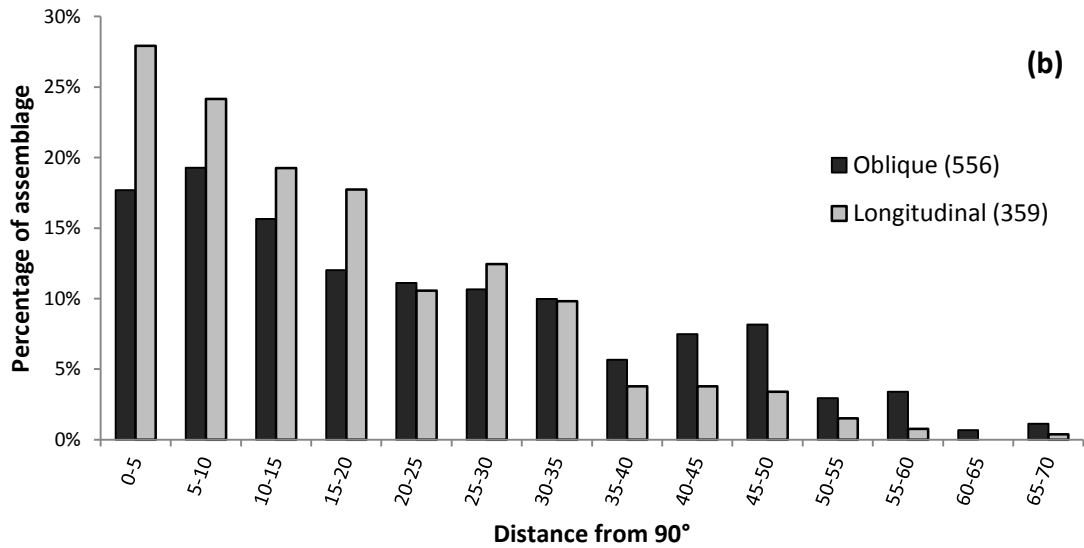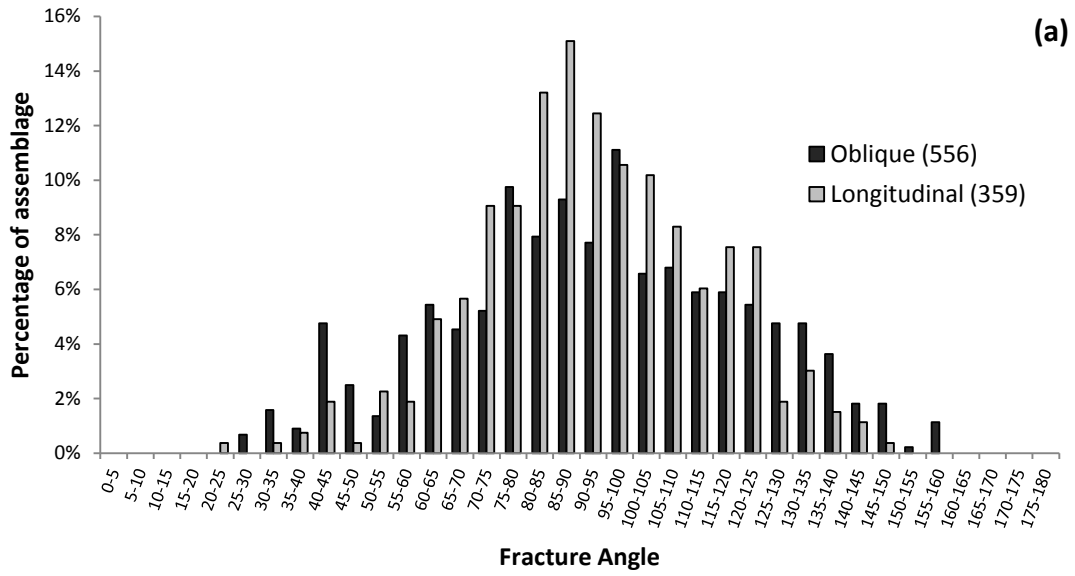
Figure 3.2: Histograms of the frequencies of fracture angle measurements on oblique and longitudinal breaks for both raw angle measurements (a) and the angle measurement distances from 90°.
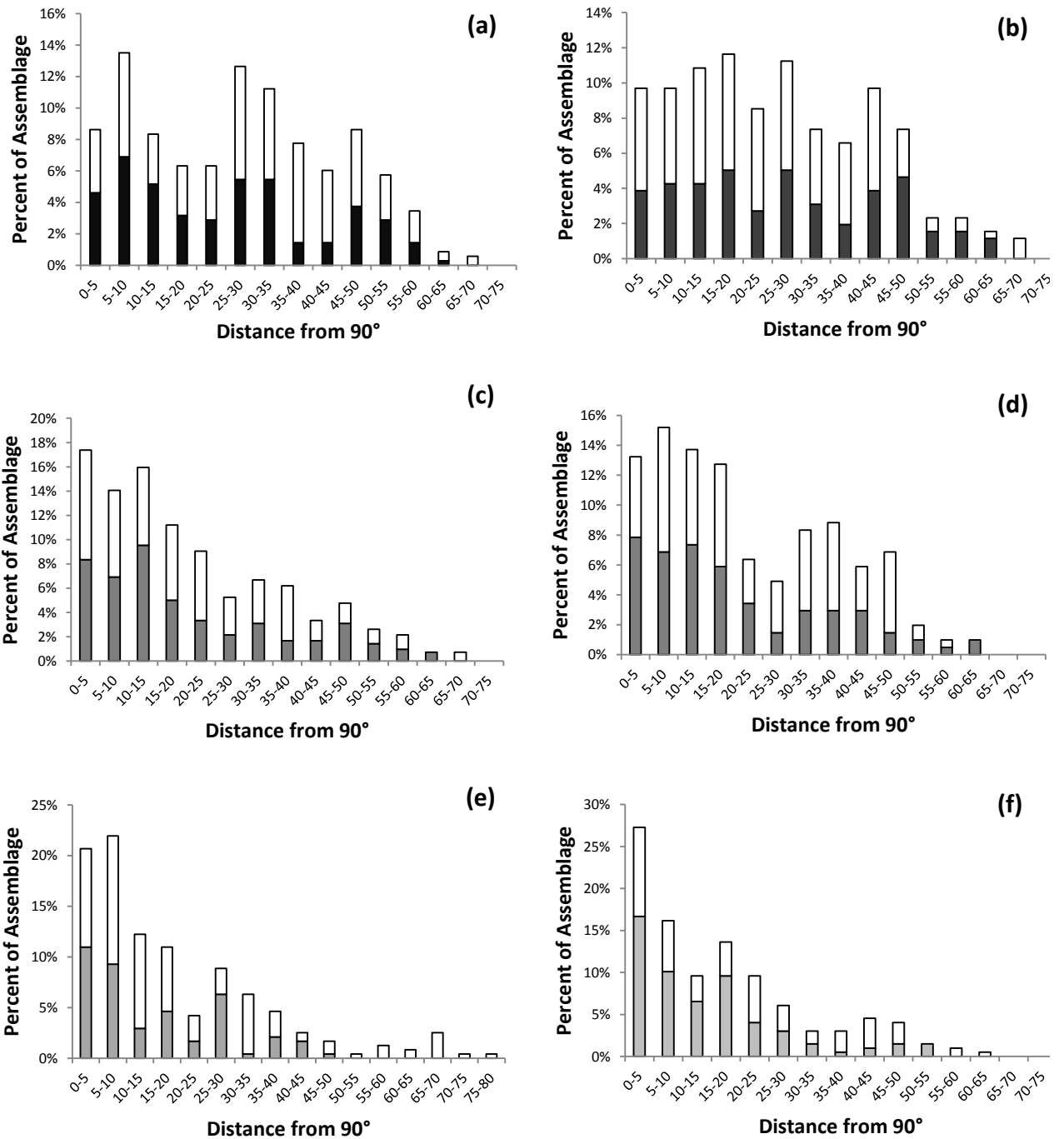
Figure 3.3: Histograms of oblique break fracture angle distances from 90° for each skeletal element. (a) Femur, (b) Humerus, (c) Tibia, (d) Radius, (e) Metatarsal, (f) Metacarpal. Acute fracture angles are in color while obtuse fracture angles are in white.
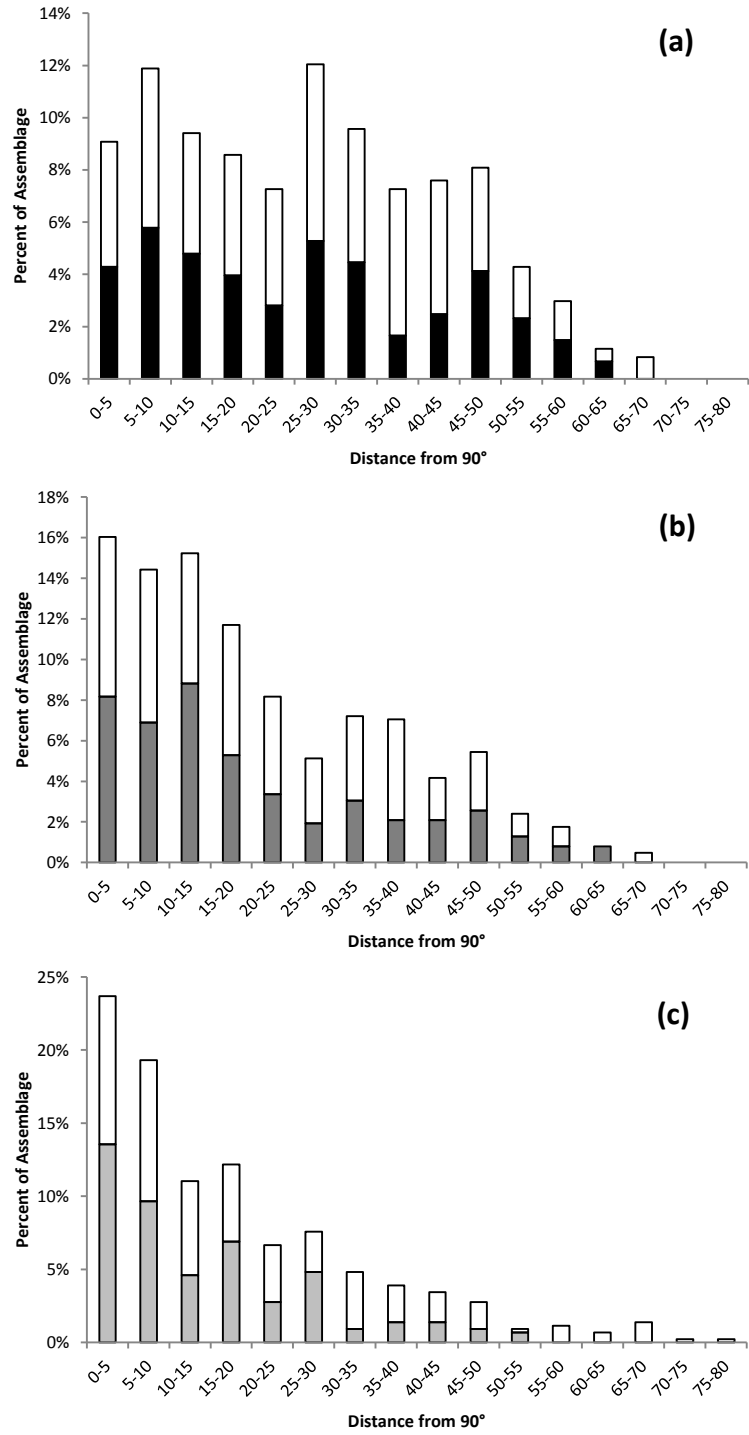
Figure 3.4: Histograms of oblique break fracture angle distances from 90° for (a) upper, (b) middle, and (c) lower limb portions. Acute fracture angles are in color while obtuse fracture angles are in white.

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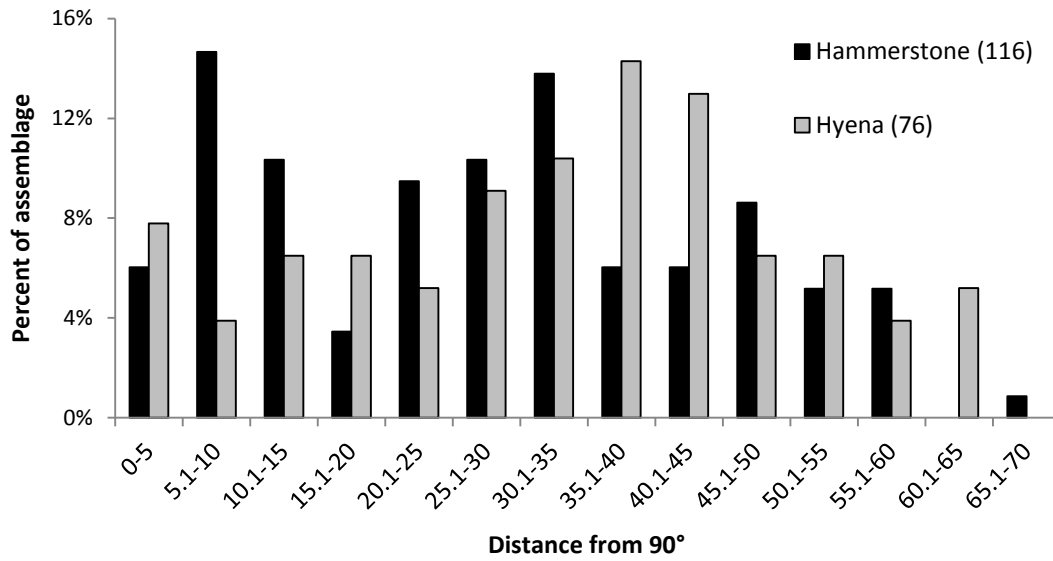
Figure 3.5. Histogram of oblique break fracture angle distances from 90° for femora broken by hammerstones and hyenas. Sample sizes are listed in parentheses.

DISSERTATION CONCLUSION

This dissertation presents new data and analyses and contributes to a large body of research on the archaeological site of Dmanisi, Georgia. The ultimate goal is to provide evidence that supports the interpretations that the faunal material was not deposited by colluvial or fluvial activity but rather was accumulated primarily by carnivores. Some hominin activity is apparent, but to a much lesser degree than carnivore activity. Other lines of evidence, such as bone fracture angles, can elucidate which agents broke the bones to access the marrow, which, in turn, can inform on carnivore-hominin interactions. This dissertation aims to answer questions that have broader impacts on early hominin archaeological research: Are there spatial patterns of the stones and faunal material that allow us to infer discrete spatial behaviors and organization by early *Homo* or early-Pleistocene carnivores? How can we use spatial evidence to break down palimpsests and complex site formation processes?

Paper 1 addresses abiotic site formation processes by examining several different lines of evidence. The orientation of archaeological material is analyzed in different ways to determine if there are preferred orientations in any of the stratigraphic layers and to identify the fabric of each layer. Most stratigraphic layers are on generally planar fabrics, where there is no preferred orientation but the dip of the stones and faunal material are on the same plane. Only one strata, B1x, has a preferred orientation, which is explained by the bones following the general structure of the erosional gully in which they were deposited. No preferred orientation in any layer is consistent with deposition by hominins and carnivores, as they typically do not orient bone and stone in certain directions when they are depositing them.

Winnowing is assessed by examining the different size classes of stones and faunal material, both piece-plotted material and material from screening and collection bags. The presence of smaller sizes of bones indicates that no differential deletion of material based on size has occurred. In the different areas analyzed in Paper 1, small bones, both complete and fragmentary are abundant in the hominin-bearing strata. Size sorting of stone or faunal material is not present and indicates that little depositional or post-depositional processes affected the smaller sized material in the assemblage. Further sampling of the screened and collection bag material is needed to fully understand the size distribution of the stones and faunal material in Block 2.

Associated and articulating elements are common throughout the stratigraphic sequence and are necessary to assess the integrity of each layer's context. If bones found in different layers refit with one another, some admixture between the two layers is present and can be a result of post-depositional reworking. In Block 2, anatomical refits and associated elements are confined to their same layers, meaning that there is not much reworking of the skeletal material after it was deposited. Some skeletal material attributed to hominins is located at higher elevations, especially in B1x, but this is a function of the shape of the layer and not of post-depositional processes.

Combining all of this evidence suggests that abiotic processes, such as fluvial or colluvial transport, were not responsible for the deposition of the stones and faunal material in the hominin-bearing layers. Colluvial transport, along with bioturbation, does seem to have played a role in the accumulation of stone material in B2. In the B1 strata, most of the taphonomic evidence points to carnivores as the main accumulating agent with some imprint by hominins and rodents and rapid deposition and little post-

depositional movement preserved the dense accumulation of bones. The second paper discusses spatial patterns that result from biotic site formation processes.

Paper 2 examines the spatial patterning of the stones and faunal material in the B1 layers of Block 2 in order to assess the contribution of biotic actors to site formation. By looking at the patterning of different subsets of the data, such as the distribution of hominin-made surface modifications, we can locate clusters of like activities and possibly infer behavior-related accumulation processes. Specifically, is there evidence that carnivores, hominins, or rodents accumulated faunal material in certain stratigraphic layers or in certain areas of Block 2 that is somehow distinguishable from the overall distribution of faunal material?

As Paper 1 demonstrated, much of the stones and faunal material in Block 2 were found in or near their original depositional context. This high degree of site integrity sets up a foundation for the spatial analysis. Some of the strata in Block two, B2-B4, are in disturbed contexts, as medieval storage pits have deleted a possibly large amount of stones and faunal material, which makes a spatial analysis difficult. The B1 strata are less affected by these storage pits, especially in the strata with the densest accumulations, B1y and B1x.

Multiple spatial analyses are used to test the differences in the distributions of each subset of data against its parent assemblage. With the exception of coprolites, all assemblages support the null hypothesis and follow the general distribution of their parent material. Despite not returning statistically significant differences, carnivore bones are more prevalent in B1x and B1y, and sparse throughout, whereas stone lithic artifacts

are nearly absent in B1x and B1y, but present throughout B1. The clustering of coprolites in an area where relatively few bones are present could indicate some differential use of space by carnivores. Hyenas have been observed to use latrines within and outside of their dens, but a further analysis of the coprolites is necessary to fully understand their contribution.

This distribution of faunal material points to carnivores as the main accumulating agent of the faunal assemblage, with some contributions by hominins. Parts of the stone assemblage, i.e. stone tools and flakes, are clearly created by hominins, but further analyses on the stone material are needed to confidently identify if the cobbles were manuports. In any case, intraspecific and interspecific competition by carnivores, along with hominin-carnivore competition, likely resulted in the accumulation of much of the stones and faunal material in Block 2.

Paper 3 offers an alternative approach to examining the contribution of hominins and carnivore to faunal assemblages by looking at fracture angles on long bones. Even today, humans and carnivores access marrow by cracking open long bones of their prey. Marrow is a valuable fatty resource that supplements a diet of meat. Previous studies have suggested that it is possible to discern between bone breakage assemblages created by humans using hammerstones and by hyenas (Alcántara-García et al. 2006; de Juana and Domínguez-Rodrigo 2011). We contribute a large dataset from a new taxon (Rocky Mountain elk) to the growing bank of bone breakage studies and introduce new analytical methodology for analyzing fracture angles.

As we performed our analysis, we began to wonder if different variables were affecting our results, e.g. the goniometer measurements themselves, the age of the individual, the freshness of the bone, the skeletal element, etc. In order to test these concerns, we ran groupwise and pairwise permutation tests since most of the resulting distributions were non-normal. We tested intra- and inter-observer first to determine if consistency and replicability were an issue. No differences were found among observers or within observers.

Within the hammerstone created assemblage, acute and obtuse angles had statistically different means so each angle type was tested separately. In addition, oblique and longitudinal break orientations resulted in significant differences, which were also separated for each test. Several factors resulted in no significant difference, thus not having a major effect in the resulting fracture angles: Whether the bone was struck midshaft or at more than one location, whether the bone was fresh or frozen prior to breakage, whether the bone was from an adult or juvenile, and whether the break length was smaller than 4 cm or larger than 4 cm. Whether the break was either on a long bone shaft fragment or a fragment containing an epiphysis did result in significant differences, but we suspect that this is a byproduct of measuring bias, since it is more difficult to measure all breaks on epiphyseal fragments due to the shape of the fragment.

We did find significant differences between the different skeletal elements and limb portions, which indicates that perhaps bones break differently depending on their morphology and cortical bone thickness. Upper limb bones (femora and humeri) tend to have fracture angles further from 90°, followed by middle limb bones (radii and tibiae) and lower limb bones (metapodia), the latter of which have fracture angles closest to 90°.

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This has major implications for how we analyze the bone breakage assemblages and perhaps it is necessary to only compare like limb portions to each other, so correct skeletal element identification becomes very important.

Comparing fracture angles between hammerstone created and hyena created assemblages returned mixed results, as three of the four pairwise comparisons were not significantly different. Our hyena sample, however, produced fracture angles further from 90° than the hammerstone sample, which is the opposite of what was found in previous studies (Alcántara-García et al. 2006). Our results are preliminary since we only have one skeletal element, so an expanded study is necessary to fully understand and compare the assemblages created by these two agents.

Ultimately, this study contributes a large sample of a previously unstudied taxon and size class. Further studies on interspecific variation to determine if the taxa affect the fracture angles are needed, since there is great variation in size and morphology of long bones between mammalian families. In any case, this paper introduces new analytical framework for studying fracture angles and the variables that can potentially affect bone breakage.

This dissertation offers new insights into the site formation processes active at Dmanisi and the potential for further analysis of carnivore-hominin interactions. Though there is no clear evidence of hominins organizing any kind of living space, perhaps we do see some organizational behavior of bone collecting carnivores, which has major implications for carnivore space use in the Caucasus around 1.8 Ma. Competition

between hominins and carnivores is present in some capacity, though perhaps a more interesting dynamic is the competition between different carnivore species, as a diverse group of apex predators were living in this area. These spatial analyses used in tandem with taphonomic analyses should elucidate these interactions and allow for a better understanding of the environment in which these hominins lived and died.

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