CONTROLLED BUTCHERY OBSERVATIONS AS A MEANS FOR
INTERPRETING OKOTE MEMBER HOMININ CARNIVORY AT KOOBI FORA,
KENYA

by

Stephen Ryan Merritt

A dissertation submitted to the
Graduate School-New Brunswick
Rutgers, The State University of New Jersey
in partial fulfillment of the requirements
for the degree of
Doctor of Philosophy
Graduate Program in Anthropology
written under the direction of J.W.K. Harris
and Robert Blumenshince
and approved by

____________________________________
____________________________________
____________________________________

New Brunswick, New Jersey
January, 2011
ABSTRACT OF THE DISSERTATION

CONTROLLED BUTCHERY OBSERVATIONS AS A MEANS FOR INTERPRETING OKOTE MEMBER HOMININ CARNIVORY AT KOOBI FORA, KENYA

by

Stephen Ryan Merritt

Dissertation Director:

J.W.K. Harris

Three archaeological assemblages from Okote Member (1.5 Ma) deposits at Koobi Fora, Kenya described by Pobiner (2007, Pobiner et al., 2008) have well preserved cortical surfaces that bear abundant hominin butchery traces on large and small mammalian taxa, minimal carnivore tooth marking, and lack in situ lithic materials. Pobiner suggests that Homo erectus generally enjoyed primary access to carcass resources with a traditional assemblage-scale analysis of butchered specimens and anatomical interpretations of cut mark location. Bunn (1981, 1994) proposes a foraging strategy for Okote hominins that links core tool butchery and curation to locally unavailable stone raw material sources in the Ileret and Koobi Fora areas of the Eastern Turkana basin. Evidence of core tool use is interpreted from the presence of wide, shallow cut marks on large animals bones. To evaluate these interpretations of hominin carnivory and bring greater resolution to archaeofaunal cut mark interpretation, I
undertook a series of actualistic butchery experiments to document how tool type (flake versus Oldowan core), butchery action (skinning, defleshing bulk tissue, defleshing scrap tissue, disarticulation) and animal size (goat versus cow) influence skeletal patterns of cut mark location, and to construct general models of cut mark cross-sectional size and the geometric organization of cut mark clusters that can discriminate these independent variables. Results indicate that tool type cannot be identified in any analysis, and that animal size influences cut mark size and organization, falsifying Bunn’s hypothesis of core tool use. Skinning and disarticulation produce wide and deep cut marks that can be distinguished from defleshing, although the amount of tissue removed (defleshing bulk versus scrap) cannot be determined from cut mark size or cluster organization. All three mark categories occur at distinct skeletal locations, but disarticulation and defleshing co-occur on the elbow. However, these actions can be distinguished on the elbow when cut mark cluster geometry is considered. A model that identifies hominins’ early access to carcass resources from elbow specimens with evidence of defleshing and disarticulation versus late access from disarticulated elbow specimens brings increased behavioral resolution to cut mark interpretation and supports previous findings of Okote hominins’ primary carcass consumption.
Acknowledgements

During my time at Rutgers I learned from my social and intellectual interaction with both students and faculty in the Anthropology Department. Primarily, I would like to thank my main advisors for their significant influence on my development. Jack Harris introduced me to fieldwork at Koobi Fora, and his passion for being in the field has been infectious. Rob Blumenschine’s critical perspective is inspirational and I feel lucky to have spent time observing the modern landscape with him. My other committee members, Susan Cachel and Ahmed Elgammal also deserve thanks for their help and inspiration. My fellow students have also helped and influenced me in so many ways, academic and otherwise. Dave Braun and Kat Underwood Braun deserve special thanks for inviting me out to FwJj 20; it made my actualistic butchery work possible and certainly a lot more fun. Needless to say, none of this work would have been possible without the tireless Dassenech butcher, Andrew. Briana Pobiner has been a great help to me from my first landrover driving lesson, to collaborations on early butchery experiments, and generously sharing her detailed and careful analysis of the Koobi Fora archaeofaunas. Mike Pante aside from being a good friend, is a great colleague in the field and the lab. Jack and Chris McCoy, Emmanuel Ndiema and Rhonda Quinn also deserve thanks for their kind words and support over the years. I thank Ryne Palombit and Marc Shur for kindly inviting me to stay at Segera Ranch when I was searching for a place to conduct my pilot research, and John Henry Rugierri and his wife Sarah for welcoming me and having me back to visit and spend time at their amazing place. Purity Kiura, the Director of the Archaeology Division at the National Museums of Kenya and Omar Idle Farrah, the Director General of NMK deserve thanks for their help with logistics at NKK. Paul
Watene and Ben Sila were great friends in the field and a tremendous help in the lab.

Finally, I thank and acknowledge the financial support of Rutgers University, the Anthropology Department and the Center for Human Evolutionary Studies at Rutgers.

This dissertation would have not been possible without the encouragement and loving support of my whole family, particularly my mother and grandfather. But without doubt I have to extend the deepest gratitude to my fiancée Robyn for her unwavering support and putting up with all those summers in the field and distracted moments away from my true love.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>ABSTRACT</th>
<th>ii</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>iv</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>vi</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>x</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>xv</td>
</tr>
</tbody>
</table>

**CHAPTER 1: The conceptual framework for interpreting archaeological traces of Butchery**

<table>
<thead>
<tr>
<th>Introduction</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>The nature of the evidence</td>
<td>3</td>
</tr>
<tr>
<td>Identifying hominin actors from modified fauna</td>
<td>9</td>
</tr>
<tr>
<td>The function of analogy in zooarchaeological interpretation</td>
<td>13</td>
</tr>
<tr>
<td>Putting taphonomic theory into zooarchaeological practice</td>
<td>18</td>
</tr>
<tr>
<td>Establishing relational analogies</td>
<td>18</td>
</tr>
<tr>
<td>Ethnoarchaeology’s contribution to the study of ancient behavior</td>
<td>25</td>
</tr>
<tr>
<td>Using Gifford-Gonzalez’s hierarchy of relational analogies</td>
<td>30</td>
</tr>
<tr>
<td>Conclusion</td>
<td>34</td>
</tr>
</tbody>
</table>

**CHAPTER 2: Experimental butchery factors’ influence on cut mark cross-sectional size: implications for Early Stone Age carnivory**

<table>
<thead>
<tr>
<th>Abstract</th>
<th>38</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>39</td>
</tr>
<tr>
<td>Materials and Methods</td>
<td>42</td>
</tr>
<tr>
<td>Experimental design</td>
<td>42</td>
</tr>
<tr>
<td>Experimental butchery procedure</td>
<td>43</td>
</tr>
<tr>
<td>Bone specimen preparation</td>
<td>45</td>
</tr>
<tr>
<td>Experimental cut mark identification, molding and measurement</td>
<td>46</td>
</tr>
<tr>
<td>Hypotheses tested</td>
<td>47</td>
</tr>
<tr>
<td>Results</td>
<td>49</td>
</tr>
<tr>
<td>Flake versus core butchery time</td>
<td>49</td>
</tr>
<tr>
<td>Cut mark size difference across single-factor categories</td>
<td>50</td>
</tr>
<tr>
<td>Cut mark size across bone portions of different density</td>
<td>52</td>
</tr>
<tr>
<td>Cut mark size differences per tool</td>
<td>53</td>
</tr>
<tr>
<td>Cut mark size differences through the butchery sequence</td>
<td>54</td>
</tr>
<tr>
<td>Discrimination of flake and core tool marks in a stratified sample</td>
<td>55</td>
</tr>
<tr>
<td>Discussion</td>
<td>56</td>
</tr>
<tr>
<td>Tool efficiency</td>
<td>56</td>
</tr>
<tr>
<td>Factors influencing cut mark cross-sectional size</td>
<td>57</td>
</tr>
<tr>
<td>Conclusion</td>
<td>60</td>
</tr>
<tr>
<td>Using cut mark cross-section to help interpret ESA hominin carcass access</td>
<td>63</td>
</tr>
</tbody>
</table>

**CHAPTER 3: The utility of cut mark cluster geometry for distinguishing flake versus core tool butchery and the amount of flesh removed**

<table>
<thead>
<tr>
<th>Abstract</th>
<th>89</th>
</tr>
</thead>
</table>
List of Figures

Figure 2-1: Box and whisker plots show the distribution of experimental tool edge angle across tool type, animal size class, and butchery action factor categories. 66

Figure 2-2: Box and whisker plots show the distribution of experimental tool weight across tool type, animal size class, and butchery action factor categories. 67

Figure 2-3: Photograph of the transverse skinning incision made with a stone tool on a cow distal metapodial. 68

Figure 2-4: Typical muscle scrap amount and location shown on a goat left forelimb, lateral view. 69

Figure 2-5: Typical muscle scrap amount and location shown on a goat left forelimb, medial view. 70

Figure 2-6: Typical muscle scrap amount and location shown on a goat left hindlimb, lateral view. 71

Figure 2-7: Typical muscle scrap amount and location shown on a goat left hindlimb, medial view. 72

Figure 2-8: Schematic of cut mark cross-section. 73

Figure 2-9: Box and whisker plots show the distribution of cut mark width across tool type, animal size class, and butchery action factor categories. 73

Figure 2-10: Box and whisker plots show the distribution of cut mark depth across tool type, animal size class, and butchery action factor categories. 74

Figure 2-11: Box and whisker plots show the distribution of defleshing cut mark width across long bone portion categories. 75

Figure 2-12: Box and whisker plots show the distribution of defleshing cut mark depth across long bone portion categories. 76

Figure 2-13: Scatter plot matrix comparing tool variables against average cut mark size per trial. 77

Figure 2-14: Scatter plot matrix comparing tool variables against average cut mark size in skinning and disarticulation trials. 78

Figure 2-15: Scatter plot matrix comparing tool variables against average cut mark size on MSH portions of defleshing trials. 79

Figure 2-16: Box and whisker plots showing the distributions of cut mark width and depth on different carcass segments for cow trials where butchery sequence was experimentally manipulated. 80

Figure 2-17: Box and whisker plots showing the distributions of cut mark width and depth according to the order in which forelimbs, hindlimbs and pelves were butchered in cow trials that experimentally manipulated the butchery sequence. 81

Figure 2-18: Box and whisker plot showing the distribution of MSH defleshing cut mark width across size class by tool type factor groups. 82

Figure 2-19: Box and whisker plot showing the distribution of MSH defleshing cut mark depth across size class by tool type factor groups. 82

Figure 3-1: Box and whisker plots of experimental tool edge angle in degrees across animal size class, defleshing action, and tool type factor categories. 125

Figure 3-2: Distribution of experimental tool weight in grams across animal size class, defleshing action, and tool type factor categories. 126
Figure 3-3: Example cut mark cluster mold.

Figure 3-4: Distributions of butchery time in minutes per trial across treatment categories.

Figure 3-5: Distributions of cut mark count per cluster across animal size class and defleshing action categories.

Figure 3-6: Distributions of cut mark count in multiple mark clusters across animal size class and defleshing action categories.

Figure 3-7: Distributions of cut mark count per cluster across animal size class and tool type categories.

Figure 3-8: Distributions of cut mark count in multiple mark clusters across animal size class and tool type categories.

Figure 3-9: Distributions of cut mark count per cluster comparing defleshing across cow long bone shaft portions.

Figure 3-10: Distribution of cut mark count per cluster comparing defleshing across goat long bone shaft portions.

Figure 3-11: Distributions of cut mark count per cluster comparing tool types on cow long bone shaft portions.

Figure 3-12: Distributions of cut mark count per cluster comparing tool types on goat long bone shaft portions.

Figure 3-13: Cluster area (mm$^2$) distributions across animal size and defleshing action categories.

Figure 3-14: Cluster area (mm$^2$) distributions across animal size and tool type categories.

Figure 3-15: Cluster area (mm$^2$) distributions comparing defleshing actions on cow long bone shaft portions.

Figure 3-16: Cluster area (mm$^2$) distributions comparing defleshing actions on goat long bone shaft portions.

Figure 3-17: Cluster area (mm$^2$) distributions comparing tool types on cow long bone shaft portions.

Figure 3-18: Cluster area (mm$^2$) distributions comparing tool types on goat long bone shaft portions.

Figure 3-19: Singleton cut mark length (mm) distributions across animal size and defleshing action categories.

Figure 3-20: Singleton cut mark length (mm) distributions across animal size and tool type categories.

Figure 3-21: Distributions of median cut mark length (mm) per multiple mark cluster across animal size and defleshing action categories.

Figure 3-22: Distributions of median cut mark length (mm) per multiple mark cluster across animal size and tool type categories.

Figure 3-23: Distributions of median cut mark length (mm) per multiple mark cluster comparing defleshing actions on cow long bone portions.

Figure 3-24: Distributions of median cut mark length (mm) per multiple mark cluster comparing defleshing actions on goat long bone portions.

Figure 3-25: Distributions of median cut mark length (mm) per multiple mark cluster comparing tool types on cow long bone portions.

Figure 3-26: Distributions of median cut mark length (mm) per multiple mark cluster comparing tool types on goat long bone portions.
Figure 3-27: Distribution of cut mark length standard deviation (mm) per multiple mark cluster across animal size and defleshing actions.

Figure 3-28: Distribution of cut mark length standard deviation (mm) per multiple mark cluster across animal size and tool types.

Figure 3-29: Distribution of cut mark length standard deviation (mm) per multiple mark cluster comparing defleshing actions on cow long bone shaft portions.

Figure 3-30: Distribution of cut mark length standard deviation (mm) per multiple mark cluster comparing defleshing actions on goat long bone shaft portions.

Figure 3-31: Distribution of cut mark length standard deviation (mm) per multiple mark cluster comparing tool types on cow long bone shaft portions.

Figure 3-32: Distribution of cut mark length standard deviation (mm) per multiple mark cluster comparing tool types on goat long bone shaft portions.

Figure 3-33: Distribution of standard deviation of cut mark angle (degrees) per multiple mark cluster across animal size and defleshing action categories.

Figure 3-34: Distribution of standard deviation of cut mark angle (degrees) per multiple mark cluster across animal size and tool type categories.

Figure 3-35: Distribution of standard deviation of cut mark angle (degrees) per multiple mark cluster comparing defleshing actions on cow long bone portions.

Figure 3-36: Distribution of standard deviation of cut mark angle (degrees) per multiple mark cluster comparing defleshing actions on goat long bone portions.

Figure 3-37: Distribution of standard deviation of cut mark angle (degrees) per multiple mark cluster comparing tool types on cow long bone portions.

Figure 3-38: Distribution of standard deviation of cut mark angle (degrees) per multiple mark cluster comparing defleshing actions on goat long bone portions.

Figure 3-39: Scatter plot of the first two principal component scores in the cow multiple mark cluster sample.

Figure 3-40: Scatter plot of the first two principal component scores in the cow multiple mark cluster sample.

Figure 3-41: Distributions of cluster attributes across cow carcass segments.

Figure 3-42: Distributions of cluster attributes across cow carcass segments listed by the order in which butchery occurred.

Figure 3-43: Scatter plot of postmortem time versus cluster area per carcass segment listed by trial.

Figure 4-1: Partly consumed female eland carcass.

Figure 4-2: Butchery decision schematic.

Figure 4-3: Early hominin access consumption sequence.

Figure 4-4: Late hominin access consumption sequence.

Figure 4-5: Cut mark width on elbow portions in cow trials.

Figure 4-6: Cut mark depth on elbow portions in cow trials.

Figure 4-7: Cut mark width on elbow portions in goat trials.

Figure 4-8: Cut mark depth on elbow portions in goat trials.

Figure 4-9: Cut mark count in cow clusters across elbow portions and butchery
Figure 4-10: Area of cow clusters across elbow portions and butchery actions.
Figure 4-11: Median cut mark length in cow clusters across elbow portions and butchery actions.
Figure 4-12: Standard deviation of cut mark length in cow clusters across elbow portions and butchery actions.
Figure 4-13: Standard deviation of cut mark angle in cow clusters across elbow portions and butchery actions.
Figure 4-14: Cut mark count in cow clusters across elbow portions, skeletal locations and butchery actions.
Figure 4-15: Area of cow clusters across elbow portions, skeletal locations and butchery actions.
Figure 4-16: Median cut mark length in cow clusters across elbow portions, skeletal locations and butchery actions.
Figure 4-17: Standard deviation of cut mark length in cow clusters across elbow portions, skeletal locations and butchery actions.
Figure 4-18: Standard deviation of cut mark angle in cow clusters across elbow portions, skeletal locations and butchery actions.
Figure 4-19: Cut mark count in goat clusters across elbow portions and butchery actions.
Figure 4-20: Area of goat clusters across elbow portions and butchery actions.
Figure 4-21: Median cut mark length for goat clusters across elbow portions and butchery actions.
Figure 4-22: Standard deviation of cut mark length for goat clusters across elbow portions and butchery actions.
Figure 4-23: Standard deviation of cut mark angle for goat clusters across elbow portions and butchery actions.
Figure 4-24: Cut mark count in goat clusters across elbow portions, skeletal locations and butchery actions.
Figure 4-25: Area of goat clusters across elbow portions, skeletal locations and butchery actions.
Figure 4-26: Median cut mark length in goat clusters across elbow portions, skeletal locations and butchery actions.
Figure 4-27: Standard deviation of cut mark length in goat clusters across elbow portions, skeletal locations and butchery actions.
Figure 4-28: Standard deviation of cut mark angle in goat clusters across elbow portions, skeletal locations and butchery actions.
Figure 5-1: Map of the sub-regions of Koobi Fora in the East Turkana basin.
Figure 5-2: Specimen 672 from GaJi 14.
Figure 5-3: Specimen 1034 from GaJi 14.
Figure 5-4: Specimen 637 from GaJi 14.
Figure 5-5: Specimen 1025d form GaJi 14.
Figure 5-6: Specimen 1007 from GaJi 14.
Figure 5-7: Specimen 902 from GaJi 14.
Figure 5-8: Specimen 7 from GaJi 14.
Figure 5-9: Butchered NISP and MNE from GaJi 14.
Figure 5-10: Specimen 101a from GaJi 14. 296
Figure 5-11: Specimen 1064 from GaJi 14. 297
Figure 5-12: Specimen 1101 from FwJj 14A. 298
Figure 5-13: Specimen 668 from FwJj 14A. 298
Figure 5-14: Specimen 1024-97 from FwJj 14A. 299
Figure 5-15: Specimen 1203a from FwJj 14A. 299
Figure 5-16: Butchered NISP and MNE from FwJj 14A. 300
Figure 5-17: Specimen 1022-97 from FwJj 14A. 301
Figure 5-18: Specimen 103 from FwJj 14A. 302
Figure 5-19: Specimen 5220 from FwJj 14B 303
Figure 5-20: Specimens 3097, 5222 and 3124 from FwJj 14B. 304
Figure 5-21: Specimen 3132 from FwJj 14B. 305
Figure 5-22: Specimen 5124 from FwJj 14B. 305
Figure 5-23: Butchered NISP and MNE from FwJj 14B. 306
Figure 5-24: Specimen 5128 from FwJj 14B. 307
Figure 5-25: Specimen 6090a from FwJj 14B. 308
Figure 5-26: Specimen 3090 from FwJj 14B. 309
Figure 5-27: Specimen 5099 from FwJj 14B. 310
Figure 5-28: Specimen 5067 from FwJj 14B. 311
Figure 5-29: Specimen 5117 from FwJj 14B. 311
Figure A-1: Left elbow joint structure. 334
Figure A-2: Left elbow joint. 335
Figure A-3: Deep structures of the right forearm, lateral aspect. 336
Figure A-4: Superficial structures of the right forearm, lateral aspect. 337
Figure A-5: Deepest structures of the right forearm, medial aspect. 338
Figure A-6: Deeper structures of the right elbow and forearm, medial aspect. 339
Figure A-7: Deep Structures of the elbow and forearm of the right thoracic limb, medial aspect. 340
Figure A-8: Superficial structures of the arm and forearm, right thoracic limb, medial aspect. 341
Figure A-9: Deeper structures of the right lateral shoulder. 342
Figure A-10: Deep structures of the right lateral shoulder. 343
Figure A-11: Superficial structures of the lateral shoulder of the right thoracic limb. 344
Figure A-12: Vessels, nerves and muscles of the right thoracic limb, elbow, medial aspect. 345
Figure A-13: Vessels and nerves of the medial shoulder and arm, right thoracic limb. 346
Figure A-14: Brachial plexus and adjacent structures of the left thoracic limb, medial aspect. 347
List of Tables

Table 2-1: Experimental trials included in this study cut mark cross section study. 83
Table 2-2: Two-factor ANOVA with interaction and Kruskal-Wallis results for differences in tool edge angle across animal size class, butchery action and tool type treatment groups. 84
Table 2-3: Two-factor ANOVA with interaction and Kruskal-Wallis results for differences in tool weight across animal size class, butchery action and tool type treatment groups. 84
Table 2-4: Two-factor ANOVA with interaction on defleshing trial time across tool type and animal size class treatment groups. 84
Table 2-5: Two-factor ANOVA with interaction on the logarithm of average cut mark width (top) and depth (bottom) per tool across animal size class, butchery action and tool type treatment groups. 85
Table 2-6: Bone portion density values. BMD values from *C. taurinus* (Lam *et al.*, 1999) are compared with goat and cow mean cut mark width per portion. 86
Table 2-7: Correlation between tool variables and average cut mark size. 87
Table 2-8: Cow butchery trials used in tool attrition investigation. 87
Table 2-9: Correlation of postmortem time and mean cut mark width and depth per segment. 88
Table 2-10: Classification of MSH defleshing cut marks with discriminant analysis using log width and log depth. 88
Table 3-1: Experimental defleshing trials organized by treatment category. 149
Table 3-2: Pearson’s correlation values for tool attributes and butchery time per trial. 149
Table 3-3: Cluster count across experimental treatment categories. 150
Table 3-4: Cluster count per long bone portion across experimental treatment categories. 150
Table 3-5: Pearson’s correlation values for log transformed multiple mark cluster attributes. 151
Table 3-6: Principal component analysis results on standardized, log transformed multiple mark cluster attributes. 152
Table 3-7: Error rates from linear discriminant analyses on log transformed cluster variable pairs for all multiple mark clusters, long bone shaft clusters, and on the first 3 principle component scores in the multiple mark cluster sample. 153
Table 3-8: Cow trials used in butchery order analysis. Postmortem time lists the elapsed time in minutes from slaughter to completion of the butchery trial. Cut mark count, cluster area (mm²), cut mark length standard deviation (mm) and cut mark angle standard deviation (degrees) columns list median values per segment. 154
Table 3-9: Correlation analysis for postmortem time and median cluster value per carcass segment. 154
Table 4-1: The proportion of butchery trials where disarticulation and defleshing cut marks occur according to carcass size and bone portion. 229
Table 5-1: Taxonomic list for Okote member assemblages. 286
Table 5-2: Butchered specimen list for GaJi 14. 287
Table 5-3: Butchered specimen list for FwJj 14A. 288
Table 5-4: Butchered specimen list for Fwjj 14B. 289
Table 5-5: Early, middle and late butchery stage actions. 290
Table 5-6: Count of butchered NISP and MNE by size class and butchery action sequence at GaJi 14. 294
Table 5-7: Elbow specimen description and cluster diagnosis. 295
Table 5-8: Count of butchered NISP and MNE by size class and butchery action sequence at FwJj 14A. 300
Table 5-9: Count of butchered NISP and MNE by size class and butchery action sequence at FwJj 14B. 306
Chapter 1: The conceptual framework for interpreting archaeological traces of butchery

Introduction

Discoveries of hominin-modified bone from Pliocene archaeological localities in Ethiopia extend the archaeofaunal record of hominin activity back to 2.6 million-years-ago (Ma), aligning the earliest traces of stone tool manufacture in antiquity with evidence of their use by the genus *Homo* (de Heinzelin *et al.*, 1999, Dominguez-Rodrigo *et al.*, 2005, Semaw *et al.*, 2003). But the recent description of two specimens with apparent traces of defleshing and fragmentation from 3.4 Ma sediments at Dikika, Ethiopia challenges convention by interpreting stone tool use during carnivorous foraging by *Australopithecus afarensis* (McPherron *et al.*, 2010). The Dikika specimens may not truly represent the earliest hominin butchered evidence (Dominguez-Rodrigo *et al.*, 2010), but the controversy surrounding their interpretation illuminates the interpretive challenges that arise when attempting to reconstruct a rich picture of ancient hominin ecology from zooarchaeological evidence. How can we determine if zooarchaeologically based paleoecological interpretations are correct and what sorts of inferences are required to reconstruct the contexts in which ancient tool-assisted carnivory existed?

This chapter explores the methods paleoanthropologists use to establish that barely macroscopic marks on the surfaces of fossil bone fragments were created by hominin hands wielding the earliest Oldowan stone tools. It also explores how
zooarchaeological evidence is used to investigate hominin behavior and the paleoecology of carcass consumption. Most importantly, this chapter builds a framework for the major topics investigated in this dissertation: can Oldowan flake or core cut marks be discriminated, and what are the diagnostic cut mark criteria that indicate which soft tissues were accessed during butchery? Carefully investigating these questions will improve our understanding of Oldowan tool assisted carnivory and strengthen the archaeological discrimination of whether hominins accessed complete carcasses or were restricted to scavenging from primary carnivore kills.

Archaeological bone assemblages derive ultimately from a set of living organisms, whose corporeal remains are affected peri- and postmortem by hominins, other organisms, and physical processes, and therefore preserve evidence of a range of biological, ecological and geological processes. The formation processes that generate zooarchaeological assemblages necessarily involve hominin interaction with other organisms, setting the stage for explorations into hominin paleoecology. But the interaction of these formation processes and their cumulative effects on hominin-generated bone assemblages can reduce the clarity of the archaeofaunal record as a direct signal of early hominin activity. The situation generally describes a hominin-modified bone assemblage’s taphonomic history, which following Efremov’s (1940) definition, investigates the history of processes operating immediately after an animal’s death, until it’s remains are excavated and analyzed (Behrensmeyer and Kidwell, 1985).

This chapter critically examines zooarchaeological investigations of the behavior and lifeways of early hominins, work that currently employs taphonomy as an interpretive framework and body of theory against which hypotheses of hominin activity
or ecology are tested. A partial history of zooarchaeological investigation is also reviewed, particularly early analyses which fail to meet current theoretical or methodological scrutiny, yet have generated debate and stimulated progress within the discipline. This history is examined in detail with the appearance of zooarchaeology informed by taphonomy, developed within the New Archaeology of the 1970’s and 1980’s, specifically the current theoretical perspective that places hominin behavioral traces under the analytical lens of hominin behavioral ecology and paleoecology, and investigates the past with careful study of modern analogues (Binford, 1981, Brain, 1967, 1969). A single theoretical framework relating archaeofaunal remains to the behavioral and ecological contexts of their production by hominin actors organizes the review of recent zooarchaeological debate and analyses. Finally, this framework is evaluated with respect to its applicability to the specific structure of archaeological bone assemblages.

The nature of the evidence

Zooarchaeology is the study of animal remains that have been affected by hominin behavior (Binford, 1981, Gifford-Gonzalez, 1991, Lyman, 1994, etc). This discussion focuses on the archaeofaunal remains associated with Pliocene and Early Pleistocene hominins in East and Southern Africa, excluding for the most part, zooarchaeological analyses that occur outside of Africa or in recent times. This focus should not imply a lack of research, or suggest that zooarchaeologists studying other geographic regions and time periods necessarily employ antiquated method and theory. This is especially true since many of the developments of the New Archaeology and the
some initial applications of taphonomy were presented in the context of North American zooarchaeology (Binford, 1981, Bonnichsen, 1989, Todd and Rapson, 1988). In fact, early hominin zooarchaeology as an independent research program, presents a unique set of questions and a methodology for answering them. All archaeological inquiries rely on material remains of complex behaviors that operated in the past, eliminating the possibility of direct observations of their outcome, and confining the connections between process and trace to the realm of inference (Ascher, 1961, Binford, 1981, Gifford-Gonzalez, 1991, Lyman, 1987, 1994, Watson, 1976, Wylie, 1985, 2000).

Archaeofaunal evidence is used like any other archaeological trace when describing the paleoenvironmental or paleogeographical context of hominin behavior, (i.e. Hay, 1976). Modifications on fossil bone surfaces explicitly link the bones in archaeological deposits with spatially associated stone tools (Bunn, 1981, Potts and Shipman, 1981, Blumenschine and Selvaggio, 1988). Archaeofaunal evidence records interspecies interaction via fossil bone assemblages, and is therefore involved in ecological issues regarding hominins and other members of their community.

But the zooarchaeology of early hominins presents another challenge for the analyst; the human ancestors that created the earliest archaeofaunal record represent extinct fossil species embedded in equally ancient paleocommunities. Investigating present-day evidence of complex systems operating in the past without an exact contemporary analog is difficult, but zooarchaeological research strives to answer interesting questions about our early ancestors by interpreting bone modification that represents hominins’ interaction with a portion of their contemporary fauna. Despite the emphasis early taphonomy placed on the potential loss of information through an

These research questions investigating hominin lifeways seem like logical components of the paleontological investigation of any fossil species, focusing on general paleoecology and paleobiological characteristics of subsistence. However, the archaeological record, or the observed material residue of hominin biology is in essence an ichnofossil record. This behavior-encoded data set can potentially address behavioral ecological questions, an endeavor rarely attempted with other fossil taxa. Archaeofaunal analysis can focus solely on how bone assemblages represent hominin behavior, or utilize a holistic approach to the archaeological record, examining the interplay of lithic and archaeofaunal evidence along with geologic contextual information to generate a more complete view of ancient hominin behavior. The Plio-Pleistocene archaeofaunal record of hominin bone modification includes incidental marks inflicted by hominins during the course of stone tool mediated carcass defleshing and marrow removal like cut marks and percussion marks (Bunn, 1981, Potts and Shipman, 1981, Blumenschine and Selvaggio, 1988) or bone fracture patterns (Bartram and Marean, 1999, Bunn, 1989, Morlan, 1984, Todd and Rapson, 1988), and modifications to bones possibly resulting from their use as
tools (Brain, 1989, Shipman, 1989). Exactly how these hominin behavioral traces were linked with various types of bone modification will be described below.

The zooarchaeological record possesses a spatial component that is extremely variable. In general, the Pliocene and Early Pleistocene archaeological record contains dispersed concentrations of stone tools and archaeological bones which can occur together, but also exist as spatially discrete patches, and sometimes as low-density background scatters dispersed over ancient land surfaces (Isaac, 1997, Isaac and Crader, 1981, Leakey, 1971). In parallel to zooarchaeological evidence, all archaeological assemblages (some of which may contain an archaeofaunal component) possess a unique taphonomic history. Taphonomic processes initially create an archaeological assemblage but can reduce the clarity of the encoded hominin behavioral signal as subsequent taphonomic processes operate. Similar methodological problems exist in the interpretation of hominin behavior from non-faunal archaeological assemblages, but the effects of a single taphonomic process can potentially affect faunal and non-faunal archaeological remains in different ways. Hypothetically, scavenging hyenas could distort the frequencies or absolute number of cut marked bone portions present after a hominin meal, but would probably not alter the frequencies or number of different stone flake types that generated the cut marks. This problem deals with the historical integrity of an archaeofaunal assemblage, a parameter that describes the agents responsible for generating an assemblage, where high integrity indicates an accumulation created by actors of a single taxon (Binford, 1981).

The operation of taphonomic processes can differentially affect various archaeological traces of a single behavioral event, like the stone tool mediated butchery
and hominin meat consumption described above, but the spatial patterning and
differential preservation of the archaeological record may also distort or create false
boundaries between behavioral events, a relationship called an assemblage’s resolution
(Binford, 1981). This fact is alluded to, but not fully integrated into some early
descriptions of the archaeological record that describe types of archaeological
contrasts sites with stone tools only (Type A) or osteological remains only (Type O) with
sites that contain stone tools and the faunal remains of a single organism (Type B), or
abundant tools and faunal evidence of multiple individuals (Type C). Additionally, these
types are contrasted with sites disturbed by some taphonomic process, either time-
averaged sites (Type D), or assemblages moved from their original spatial context (Type
G). In reality, these site types force a complex set of data into overly simplistic
categories. In fact, type B assemblages were described as butchery sites, while type C
assemblages were considered home bases, where groups of hominins engaged in social
behaviors centered around male meat provisioning, and the sharing of this food between
group members (Isaac, 1978). More recent approaches to the archaeological record are
explicit about the disparate means by which archaeological assemblages of similar
structure are created, and have relied more on exploring the specific attributes of
individual archaeological occurrences (Blumenschine and Peters, 1998, Kroll, 1994, Sept,
1994). These theoretical and methodological developments scrutinize archaeological
association between individual archaeological traces within an assemblage and claims
about hominin behavior that are based on these associations.
As mentioned above, hominins are the only taxa who intentionally modify and transport stone tools, but many organisms are attracted to faunal remains during the biostratinomic phase of their taphonomic history, where caloric resources like meat and mineral resources exist in association with bones (Behrensmeyer and Kidwell, 1985).

An ecological relationship between hominins and carnivores may be represented on bone specimens consumed by both taxa, since large mammalian carnivores, particularly the felids, canids and hyaenids are known to create tooth marks and patterns of damage to bones related to consumption (Binford, 1981, 1988, Blumenschine, 1986, Cruz-Uribe, 1991, Dominguez-Rodrigo, 2002, Hill, 1989, Sutcliffe, 1970 etc.). In addition to carnivores modifying individual bones, some ungulates, especially some New World deer species are known to chew bone for the mineral salts they contain (Johnson and Haynes, 1985, Lyman, 1994, Sutcliffe, 1973). Rodents also modify bone, gnawing them to curb the constant growth of their incisors (Brain, 1980, 1981), and the bone modification signatures of crocodile feeding has recently been defined, and evidence of this behavior has also been discovered in lake-shore paleogeographic settings, including on fossil hominins (Njau and Blumenschine, 2006). It is important to remember that hominins are not the only group of organisms that interact with faunal materials and modify bone surfaces. Animal taxa that fracture bones and mark their surfaces also influence their spatial patterning. This is especially apparent when bone-accumulating organisms like porcupines and other rodents who collect dry bone generate bone assemblages inside their burrows (Brain, 1980, 1981). Carnivores that consume bone like hyenas and flesh-specialists such as the felids that damage bone during feeding, also generate faunal assemblages, a fact not appreciated in early zooarchaeological analyses.
As will be discussed below, early zooarchaeological analyses assumed that all bone accumulations were the by-products of hominin carnivory (e.g. Dart, 1960), but recent methodological approaches investigate and attempt to identify the biological agents that accumulated or created spatial patterning within an assemblage (Binford, 1981, Blumenschine, 1986, Brain, 1980, 1981, Capaldo and Blumenschine, 1994, Dominguez-Rodrigo, 1999, Dominguez-Rodrigo and Piqueras, 2003, Selvaggio, 1998).

This brief review of the structure of the Plio-Pleistocene archaeological record highlights the complex nature of the zooarchaeological data set. It is easily appreciated that hominins are one of many taxa that may affect the patterning of faunal remains both at the scale of individual bone specimens or the assemblage. Zooarchaeological remains enter the fossil record through the operation of physical processes like transport, sedimentation, and diagenesis, which all introduce an element of spatial and temporal variability. When a bone assemblage is viewed with an eye toward its hominin behavioral component, the validity of archaeological association for relating sets of behavioral events and their material residues is in question without an explicit means of differentiating hominin behavior from the behavior of other organisms and the operation of abiotic processes. Essentially, any interpretation of the archaeological record demands a taphonomic interpretive framework, not only to deal with the variability in organisms’ interaction with bone, but to overcome the methodological issues within the analysis of a partial or blurry glimpse of complex behavioral systems which are sporadically recorded in a patchy geologic record.

Identifying hominin actors from modified fauna
Early zooarchaeological analyses lacked a taphonomic perspective and generated conclusions about archaeological site formation that confused hominin behavior and other taphonomic processes. Dart’s description of the osteodontokeratic culture at the South African cave site Makapansgat provides an example (Dart, 1957, 1959, 1960, etc). Dart used the fragmented bones encased in cave breccia to argue that “australopithecines had the human ability to use antelope bones other than as clubs and daggers: they used upper jaws as scrapers; horns as picks; lower jaws as blades, saws, and knives; and shoulder blades and pelvic bones as chopping tools” (Dart, 1960:134). Dart suggests that hominins used the fragmented bones, usually horncores, bulky epiphyseal fragments with pointed shaft fragments attached, mandibular tooth rows and maxillae, as tools. Moreover, these implements were intentionally manufactured by hominins that were capable of “splitting bones… [and] trimming… bones by flaking, which lead to the subsequent discovery of the trimming of stone tools” (135). It is clear that Dart believes that australopithecines generated the entire bone assemblage at Makapansgat, but criticism of his propositions which targets taphonomic ignorance as well as the unfounded social claims were not ignored by Dart (Washburn, 1957). Dart defends his analysis against claims that other agents, such as porcupines accumulated the fauna at Makapansgat, arguing that evidence of multiple fractures on many long bone fragments could not result from anything other than australopithecine tool manufacture. This zooarchaeological debate stimulated the investigation of taphonomic processes of site formation relevant to the South African cave sites, which was joined by the investigations of other researchers interested in the hominin fossils and associated stone tools (Brain,
Pioneering work by Brain (1967, 1969, 1980, 1981), along with early taphonomically-inspired zooarchaeologists put aside promoting exciting claims of blood-thirsty hominins, and employed the scientific methods of deductive reasoning and hypothesis testing that investigate hominin behavior with respect to the formation of the Makapansgat faunal assemblages. Brain argues that other agents, particularly the ancient porcupines, leopards or hyenas that inhabited the cave could have accumulated or fragmented the assemblages as a part of their natural behavior (1980, 1981).

Perhaps current analytic techniques allow unfair attacks of Dart’s work, which was still entrenched in the culture history paradigm of traditional archaeology. The Makapansgat breccia does contain hominin fossils and fragmentary animal bone in spatial association, so the desire to link broken bones as hominin dietary evidence is not illogical, especially in light of the large archaeological cave sites excavated in Europe containing firmer evidence of ancient human cave dwelling. The focus of early taphonomic research, of which Brain’s work specifically addresses the Makapansgat assemblage, highlights the main flaw in Dart’s work and the culture history approach it represents, namely the lack of investigation into alternate processes of site formation (Brain, 1981, Behrensmeyer and Dechant Boaz, 1980, Binford, 1981, 1984, Hill, 1980 etc.)

This work, which as stated above explicitly acknowledged the role of non-hominin processes in the accumulation of faunal remains, took steps to investigate specific patterns of faunal accumulation or modification and relate these to the process
responsible for their creation. The “field studies” Brain describes for shedding light on who or what is responsible for creating the bone assemblage at Makapansgat can be used to “build up an inventory of criteria whereby the various bone-collecting agencies in caves can be recognized” (Brain, 1980:129). The principle outlined is appropriate for all zooarchaeological assemblages. Exploring the damage to antelope skeletons due to either leopard predation, hyena ravaging, or rodent accumulation, and these patterns’ translation into assemblage scale skeletal part and portion frequencies via present day experiments are referred to broadly as actualistic studies (Binford, 1981, Blumenschine, 1986, Brain, 1980, 1981, Capaldo, 1997, Dominguez-Rodrigo, 1999, Fiorillo, 1989, Gifford-Gonzalez, 1991, Jones, 1981, Selvaggio, 1998, Walker and Long, 1977, etc.). This work, which follows the guidelines of middle-range theory, along with specific uses of actualistic research that address aspects of hominin behavior like carcass access and carnivory in general will be discussed in detail below.

Brain’s work showed that leopards and hyenas living around the present day South African caves will consistently destroy certain skeletal elements, typically less robust parts, and hyenas will consume many smaller and less-dense parts, creating the dense cortical bone epiphyseal fragments with attached shaft fragments that Dart described as hominin daggers (Brain, 1980, 1981). Publication of these results was an important event in the history of zooarchaeological analysis. Brain built a strong argument by creating an analogy between the present experimental process and result, and relating it to the operation of an analogous process in the creation of the Makapansgat assemblage. Brain’s (1980, 1981) work defined the concept of equifinality for taphonomic inquiries of African faunal assemblages, and at the same time, attempted
to dismiss the confusion in the relationship between formation processes and the traces they produce. The term equifinality is not used by Brain, but it’s meaning, the inability to distinguish the operation of multiple processes that generate the same outcome, is central to Brain’s argument (Gifford-Gonzalez, 1991, Rogers, 2000). Brain contributed significantly to the development of taphonomically oriented zooarchaeology in two major ways. First, by addressing the equifinality in the accumulating agent of the Makapansgat fauna, particularly carnivorous hominins or members of the order Carnivora like hyenas or leopards, Brain formalized a testable hypothesis regarding accumulation by either of these agents. Second, a means of understanding the site formation processes at work during the Pliocene of South Africa he explored modern day process-trace relationships as a proxy for analogous process-trace relationships in the past.

A common element in early zooarchaeological analyses is the lack of an interpretive framework that guides analysis, as seen in Dart’s description of the Osteodontokeratic. This discussion emphasizes the application of taphonomic theory, which demands testing of hypotheses, and forces analysts to examine the possibility that, “generally, several bone-accumulating agencies have been at work” during the formation of a faunal assemblage (Brain, 1980:129).

The function of analogy in zooarchaeological interpretation

The previous section reviewed the benefits a taphonomic perspective can afford Plio-Pleistocene zooarchaeology, without specifying the structure of taphonomic
arguments. This section examines the methods involved in creating taphonomic arguments about zooarchaeological assemblages.

A fundamental problem prevents casual interpretations of hominin behavior and all studies of past dynamics; the operation of past processes and their resultant traces cannot be observed directly or manipulated experimentally. This problem is overcome with the uniformitarian principle, which in its early stages of development in the geological sciences, was substantive, essentially arguing that past processes operate in exactly the same manner and at the same rate, as their modern counterparts (Gould, 1965, Binford, 1981). Recent applications of uniformitarianism utilize its methodological form, where the relationships between present processes and traces are used to infer the context of processes that created traces in the past like the archaeological record (Gould, 1965, Binford, 1981). The relationship between the past and present that uniformitarianism establishes is ultimately a form of analogy. The analogy employed relates observable facts with a specific structure (present-day results), with other observable facts of a similar structure (past results), and argues that the causal process generating the present results is the most parsimonious causal process of the past results (Ascher, 1961, Gould and Watson, 1982, Lyman, 1994, Wylie, 1985, 2000). The creation of analogies to study the archaeological remains of hominin behavior is stronger than simple similarity, or formal analogy, but rather demands the use of relational analogies, which have firmly established causal links between process and result (Binford, 1981, Gifford-Gonzalez, 1991, Lyman, 1994).

The analogical method of examining the past is the main tool in any investigation of the past, and plays a central role in middle-range theory, the framework from which
inferences about hominin behavior are built and tested (Binford, 1981, 2001, Tschauner, 1996). Middle-range research attempts to link the low-range static traces of past behavior with their high-range, dynamic causal processes, including biological, ecological and behavioral factors, through a series of relational analogies that comprise the middle-range (Binford, 1981).

Gifford-Gonzalez (1991) argues that due to the complex nature of biological processes, hominin behavior is embedded within multiple nested contexts. This forces middle-range inquiries to deal with the possibility of emergent processes, whose results derive from the interaction of multiple complex, interrelated processes, and have a gestalt quality in that the interaction of these processes may create results with very little resemblance to the traces of a process operating in isolation (Mayr, 1982). For this reason, a single relational analogy between past and present traces and dynamics may be too simple to accurately model these relationships. This led Gifford-Gonzalez (1989, 1991) to develop the nested hierarchy of relational analogies that bridges the gap between the archaeological static traces of hominin behavior and their complex causal processes. This is the most developed form of middle-range research, since it requires empirically demonstrated relational analogies to connect each level of inference. The analogical chain Gifford-Gonzalez (1991) proposes begins with the low-range trace (sensu Binford, 1981), the observable archaeological data, which is connected through a causal process to the effector, or the physical object which creates a trace, and the actor, or agent whose effector creates a trace. The actor, effector and trace are embedded within a behavioral context, and ultimately a social and ecological context, which are the high-range dynamics of hominin lifeways that paleoanthropologists aim to investigate.
This methodological paradigm for investigating prehistoric hominin behavior is simple and logical, but ultimately depends on establishing relational analogies between Gifford-Gonzalez’s hierarchical categories. Building these relationships involves the use of uniformitarianism and analogical arguments between adjacent categories, and support from controlled naturalistic observations and actualistic experimentation, examples of which will be discussed below.

As mentioned above, equifinality, analytically identical traces caused by different processes, is a complicating factor in investigations of the past. Middle-range research is designed to break equifinalities, and accomplishes this by studying the operation of present-day analogs of ancient trace-process relationships (Binford, 1981, Gifford-Gonzalez, 1991). Integrating empirical demonstrations of process-trace causal relationships and their relational analogies into Gifford-Gonzalez’s (1991) nested hierarchy of causal processes and contexts validates inferences about the higher-ranges of hominin behavior based on archaeological data.

Middle-range research is the most appropriate method for studying the archaeological record because it is tailored to the nature of zooarchaeological evidence. The zooarchaeological record can be thought of as the static results of the operation of complex systems of hominin behavior that are subject to the effects of taphonomic processes that differentially affect their analytic visibility. A further complication is the specificity of the higher-range processes that create the zooarchaeological record and affect the resolution and integrity of archaeological deposits. Variation in the paleolandscape location where hominins modified bone would create different ecological parameters that would trickle down through the hierarchy of contexts producing
zooarchaeological traces that are site-specific with respect to behavioral and ecological contexts, but these possibly distinct contexts may be indistinguishable at lower levels of inference. However, as with any taphonomic process the equifinality in interpretation of bone modification in different contexts is a major confounding factor in reconstructing the higher-ranges of hominin behavior.

As will be described below, the connections between the zooarchaeological static traces and the lower-level hierarchies in Gifford-Gonzalez’s (1991) framework are addressed by zooarchaeologists engaged in actualistic studies (Brain, 1981, Blumenschine, 1986, 1995, Blumenschine and Selvaggio, 1988, Capaldo, 1997, Capaldo and Blumenschine, 1994, Dominguez-Rodrigo, 1999, Domingez-Rodrigo and Piqueras, 2003 etc.), but linking these arguments through the middle-range to their place within behavioral, social and ecological contexts is still premature.

The investigation of the ecological context of hominin behavior should be possible using zooarchaeological data and taphonomic theory, which employs middle-range theory. Fundamentally, zooarchaeological evidence is appropriate for investigations of this type since archaeofaunal assemblages record the interaction of hominins with other organisms in their paleocommunities. On this scale of investigation, zooarchaeological research intersects with paleoecology, a working relationship advocated by Behrensmeyer (2000) as ecological taphonomy. Specifically using archaeofaunal evidence in this fashion can address hominin diet, the strategy hominins employed when accessing animal resources and competition between members of the carnivorous paleoguild (Gifford-Gonzalez, 1991, 1999). Compared with establishing links between archaeological data and lower-level inferences like the effector, taking
zooarchaeological analysis to the highest level of inference described by Gifford-Gonzalez, the ecological context, is difficult. Convincingly doing so requires a large set of relational analogies to provide multiple lines of evidence in support of the connection between zooarchaeological data and the selection pressures faced by Plio-Pleistocene hominins. Using Gifford-Gonzalez’s (1991) nested hierarchy of relational analogies as an organizational tool, the next section briefly reviews the attempts to interpret hominin behavior from zooarchaeological evidence at various levels of inference.

**Putting taphonomic theory into zooarchaeological practice**

*Establishing relational analogies*

When using Gifford-Gonzalez’s (1991) nested hierarchy as a tool in middle-range research, and zooarchaeology specifically, connections between levels must be established from the most specific category outward, eventually reaching the broadest context that subsumes all others (Binford, 1981, Gifford-Gonzalez, 1989, 1991). Even though this method of connecting the static traces of hominin behavior to their higher-range contexts is applicable for any archaeological investigation, it was created to deal specifically with zooarchaeological evidence, and has therefore seen the most use in this research area.

The investigation of hominin carnivory largely spurred the development of middle-range research as described above, and the zooarchaeological research demonstrating empirical links between the low and middle-ranges of trace, effector and
actor were carried out under this methodological paradigm. This work began with the investigations of marks on fossil bone surfaces that occurred in association with lithic archaeological material in many archaeological sites. Cut marks (Bunn, 1981, Potts and Shipman, 1981, Shipman et al., 1984, Walker and Long, 1977), hammerstone percussion marks (Blumenschine and Selvaggio, 1988) and percussion notches (Capaldo and Blumenschine, 1994) have been connected to hominin butchery involving stone tools. In addition, similar modifications, which exist as potential equifinalities, such as trampling marks (Behrensmeyer et al., 1986, Fiorillo, 1989, Olsen and Shipman, 1988, Shipman and Rose, 1984) and carnivore tooth marks (Blumenschine, 1995, Capaldo, 1997, Selvaggio, 1994, 2001) and notches (Blumenschine and Capaldo, 1994) have been identified, and rarely raise issues of misidentification (Blumenschine et al., 1996). But as the recent debate over the authenticity of pre-Oldowan butchery marks from Dikika points out, any contact with a sharp stone effector can create bone surface modification, but the logical anatomical positioning of butchery marks on a carcass is necessary to implicate the action of a hominin butcher (Domínguez-Rodrigo et al., 2010, McPherron et al., 2010).

The research described above that connects archaeological traces with effectors and actors engages in a type of middle-range research referred to as actualism. This methodology explicitly utilizes relational analogies to connect past traces with their effectors and actors, emphasizing accuracy and precision in the modern replications of the past situations under study (Blumenschine and Selvaggio, 1988, Blumenschine, 1995, Capaldo, 1997, Lyman, 1994). Evidence of hominin involvement in archaeofaunas was hypothesized early in paleoanthropological investigations (e. g. Dart, 1957, 1960). The
recognition of shallow, almost microscopic linear striae on fossil bone assemblages from Olduvai Gorge, Tanzania, and Koobi Fora, Kenya, led early researchers to imagine that these marks were made by hominins using stone tools to butcher the archaeologically associated bone (Bunn, 1981, Potts and Shipman, 1981). However, despite these marks’ locations on anatomical portions thought to signal either skinning, defleshing or disarticulation, empirical support for this hypothesis was needed. It was in this context that Bunn, and Potts and Shipman, (among others like Brain), conducted the first controlled actualistic experiments in taphonomy and early hominin zooarchaeology. These experiments used replicated stone tools to butcher modern animals, making cut marks in the process. Qualitative morphological similarities of scanning electron micrographs of the experimental cut marks and the archaeological marks, specifically regarding the presence of parallel internal striae and the lack of crushing, led the authors to conclude that the fossil marks were made by stone tools (effector) used by hominins (actor). A similar process was used to establish the link between percussion pits and hominin hammerstone fragmentation (Blumenschine and Selvaggio, 1988).

These studies, and others (e. g. Blumenschine, 1995, Capaldo, 1997, Selvaggio, 1994, Selvaggio and Wilder, 2001 etc.) broke a fundamental and broad-reaching equifinality between the agent of bone modification, specifically hominins versus carnivores, and showed that for archaeological faunas, both classes of actors typically contribute traces. In fact, similar techniques of middle-range research involving naturalistic observations have demonstrated that shallow scores on bone surfaces were caused by the teeth of carnivorans during feeding and/or bone consumption.

At this stage in the methodological development of the analysis of hominin butchery, it was not possible to determine the order of hominin access to carcasses, or the carcass acquisition strategy employed by hominins, since this research only demonstrated the trace-actor link. However the presence of specimens preserving overlapping cut marks and carnivore tooth marks indicated that the activity of multiple taphonomic agents operating on an assemblage or even on a single bone specimen was indeed an issue worth investigating (Blumenschine, 1988).

In addition, the presence of other bone modifications caused by natural processes like trampling and rockfall that may mimic cut marks or hammerstone fragmentation, caused concern among zooarchaeologists (Behrensmeyer et al., 1986; Fiorillo, 1989; Olsen and Shipman, 1988; Shipman and Rose, 1984). In actualistic experiments aimed at differentiating hominin stone tool cut marks and hammerstone fragmentation from ungulate trampling or natural rockfall, the researchers found significant morphological similarities between cut marks and trampling marks experimentally produced on sandy and rocky substrates (Behrensmeyer et al., 1986, Fiorillo, 1989, Olsen and Shipman, 1988, Shipman and Rose, 1984). This result is not surprising, since the effector (sharp-edged rocks) was the same, and while these authors largely urge caution in attributing individual marks to hominins or trampling agents, the random orientation and placement of trample marks can distinguish between hominin-produced cut marks and trampling. Here we obtain a glimpse of the value of context in the interpretation of zooarchaeological data suggested by Gifford-Gonzalez (1991). These studies only link
the low-range traces with their effectors and actors, but appeal to the higher-ranges, suggesting that the patterning of modification will vary in different contexts (i.e. hominin butchery should generate cut marks in anatomical locations relative to the butchery task or strategy, whereas ungulate trampling will randomly generate ‘pseudo-cutmarks’ in locations relative to the orientation of the bone and the nature of the substrate).

The work described above established the clearest and most explicit link between archaeofaunal remains and hominin activity in Plio-Pleistocene zooarchaeology. The connection of static trace only extends to the level of effector or actor, and was not confined to investigations of hominin behavior. These analogical links serve as basal facts that can be implemented in the next analytical step of Gifford-Gonzalez’s (1991) nested hierarchy.

Investigating the behavioral and ecological contexts within which archaeological traces were created involves a dramatic increase in complexity of the process-trace relationship due to numerous equifinalities introduced by different taphonomic processes. There are surely many ecological contexts that a cut mark could have been made in, and dispelling equifinalities on this scale requires many more lines of supporting evidence, as suggested by Gifford-Gonzalez (1991) with the statement, ‘bones are not enough’. Two methods of middle-range investigation are currently in practice by Plio-Pleistocene zooarchaeologists, largely focusing on the hunting versus scavenging debate of carcass access, and neither is a perfect analog for early hominin-faunal interaction.

In recognition of connecting the low-range traces of hominin behavior with their higher-range behavioral and ecological contexts, as argued by Gifford-Gonzalez (1991), in addition to the recognition that faunal assemblages are rarely acted upon by single
agents, zooarchaeologists have focused their actualistic experiments at determining the behavioral traces of hominin butchery within different contexts (Blumenschine, 1988, 1995, Capaldo, 1997, Dominguez-Rodrigo, 1997, Selvaggio, 1994). These experiments investigate hominin and carnivore damage to bone, and specifically model primary or secondary hominin access to fully-fleshed or mostly-defleshed carcasses respectively, and investigate cut marking and percussion marking relative to carnivore damage. In essence, arguments about zooarchaeological data that investigate both hominin and carnivore modifications enter into Gifford-Gonzalez’s higher ranges in inference.

These actualistic results are the next step in evaluating the larger contexts of hominin butchery, and in general find that hyena ravaging of discarded hominin-hammerstone fragmented bones will delete the less dense epiphyseal ends, and generate tooth-marked shaft fragments, removing some traces of hominin butchery (cut marks and percussion marks) from those portions (see also, Blumenschine and Marean, 1993). Additionally, hominins accessing defleshed carcasses will produce fewer cut marks, but an equal amount of percussion marks, since initial felid carcass generators are not predicted to break bones for marrow.

In sum, the actualistic work investigating the bone modifications produced in different hominin and carnivore access models suggest some general patterns, but does not reach definite conclusions about the bone modification signatures that hominins will produce when the order of access is varied (Dominguez-Rodrigo, 2002, Lupo and O’Connell, 2002, Monahan, 1999). This critique has recently been presented in the zooarchaeological literature, and heavily emphasizes the interanalyst methodological differences embedded within an argument against the actualistic method in general (Lupo
and O’Connell, 2002, but see Dominguez-Rodrigo, 2002 and O’Connell and Lupo, 2003). The differences between analyses, specifically, the use of metal knives versus stone tools in butchery experiments, and the testing of different sequences of hominin access, do not allow the comparison between different sets of experiments, and raw data is rarely included, which would partially alleviate this issue. But these studies represent an important step in using the actualistic method of middle-range research to illuminate the higher-range contexts of archaeological hominin butchery, a task that increases dramatically in complexity when moving further outward along Gifford-Gonzalez’s (1991) chain of causal links, where complex biological processes can generate emergent phenomena.

These actualistic experiments are useful in that they reaffirm the action multiple taphonomic processes during assemblage formation, and highlight equifinalities that complicate archaeological interpretations. The inability to differentiate tooth marks made by different Carnivoran taxa has been recognized (Dominguez-Rodrigo and Piqueras, 2003, Haynes, 1983, Pobiner, 2007, Selvaggio, 2001), and the cut mark traces of different stone tool classes has been investigated (Greenfield, 2006, West and Louys, 2006), but the crux of the issue lies in the interpretive uncertainty introduced when carcasses are fragmented and dispersed during consumption (Outram et al., 2005). Actualistic observations attempt to maximize the resolution of behavioral interpretations drawn from their datasets, but this modern-day precision is not automatically present in archaeological interpretations. Therefore actualism must determine whether the modern assemblages from which hypotheses are drawn are equivalent in structure to the archaeological assemblages within which these hypotheses are tested. Understanding how
to decipher the traces of behavior through the uncertainty and unidentifiability inherent to archaeological materials, especially zooarchaeological specimens, is the next step toward a secure interpretation of ancient behavior. Research into this problem has only recently begun (see Bar-Oz and Munro, 2004, Enloe, 2004, Lyman, 2005, Marean et al., 2004, Outram et al., 2005, Pickering and Egeland, 2006, Seetah, 2008).

*Ethnoarchaeology’s contribution to the study of ancient behavior*

In contrast to experimental actualistic methodologies, ethnoarchaeology is a form of middle-range research that utilizes naturalistic observation, and can collect useful data regarding hominin behavior, mainly observations of cut mark patterning by anatomical location, and transport of carcass parts from kill/field butchery locations to secondary butchery locations. Ethnoarchaeological observation is by its nature designed to construct general behavioral patterns applicable to archaeological investigations, uses relational analogy and uniformitarianism, and is therefore a valid type of middle-range research (Binford, 1981, 2001, Bunn, 1983, O’Connell et al., 1988, Yellen, 1977).

Ethnoarchaeology casts the hunter-gatherers under observation as a modern analog of early hominins, from which connections can be drawn in an attempt to connect the higher-range behavioral and ecological contexts of hominin faunal interaction with the static traces seen in the archaeofaunal record. The range of behavioral and ecological contexts that can be related to their present-day static traces using ethnoarchaeological analogs is limited by the environmental setting of the modern population. Further, naturalistic observations are not hypothetical and do not manipulate variables to establish
experimental control. Additionally, the ethnoarchaeological method of middle-range research suffers from being a fixed modern analog, that cannot be fine-tuned to test particular archaeological situations, unlike the actualistic approach, and therefore is more comparative than experimental.

Yellen (1977) outlines the various approaches for using ethnoarchaeological data to address archaeological patterns. The first and favored method is the general model approach, where the underlying principles of broad applicability are sought. This is contrasted with the buckshot approach, where portions of ethnoarchaeological data are cited in support of archaeological hypotheses.

Regardless, it may be useful to examine the bone modification traces produced by people whose subsistence consistently involves butchery in order to establish general principles and link behavioral and ecological contexts with their behavioral static traces. This issue seems to depend on a balance between the accurate and precise modeling of inferred past contexts, and the use of real-world contexts and their results, which may not be close analogs of hominin behavior.

Ethnoarchaeological observations have been conducted with many modern hunter-gatherer groups in the service of zooarchaeological research (Bartram, 1992, Brain, 1967, 1969, Bunn, 2001, Bunn et al., 1988, Gifford-Gonzalez, 1989, Hudson, 1991, Lee and Daly, 1999, O’Connell and Marshall, 1989, O’Connell et al., 1988, Stewart and Gifford-Gonzalez, 1994, Yellen, 1977), but for brevity’s sake, detailed information about only two groups, the Nunamiut and the Hadza, who have played a major role in the interpretation of Plio-Pleistocene hominin butchery, are presented.
Binford (1978, 1981) is responsible for documenting the patterns of bone modification in different contexts. The Nunamiut are an Eskimo group, who live in arctic conditions and subsist as hunter-gatherers, obtaining most of the meat in their diet from hunted caribou, although domesticated sheep are also utilized as a food resource. Binford’s (1978) analysis documents hunting methods, carcass caching and transport decisions, butchery strategy, carcass use, and their resultant modifications to bone, along with the damage inflicted on bones fed to Nunamiut dogs.

In general, Binford (1978) describes Nunamiut butchery as highly variable. The Nunamiut hunt with rifles from the backs of their snowmobiles, on foot, or with dog sleds, occasionally killing multiple caribou. When this occurs, if hunters are far from camp, and depending on the mode of transport, carcasses may be field butchered and cached in the snow for later recovery. When carcasses are fresh, meat is usually stripped from bone, and the marrow and brain consumed at the kill-butchery site, except, at times the upper limb bones (excluding the carpals, metacarpals and phalanges) may be returned to camp. In general, as more carcasses are butchered, the number of lower limb bones discarded at the primary butchery site increases. The basic pattern, constructed as a general utility index suggests that cranial and lower limb bones will be discarded during initial butchery, while the upper limbs and other axial bones will be returned to camp. The general pattern Binford (1978) describes is also complicated by the season and the Nunamiut practice of drying meat. Field butchery of frozen, cached carcasses is much more difficult than supple, fresh carcasses, so frozen carcasses are more likely to be returned to camp for further processing and chopped through midshafts, as opposed to butchered in relation to muscle attachments. Binford (1978) describes cut mark location
as summed marks on all bone specimens relative to anatomical location. These data are lengthy, but in general, cut marks occur much more frequently on the near epiphyseal portions of bones where large muscle groups attach, and on or around the articular surfaces of joints, which Binford (1978) argues to result from defleshing and dismemberment respectively.

The Hadza, another well-studied hunter-gatherer group, live in Tanzania, and provide the next example of an ethnoarchaeological description of hominin butchery. These observations also record bone modification, especially how it relates to the three classes of Hadza sites of bone deposition (Bunn, 2001, Bunn et al., 1988, Lupo, 2001, O’Connell et al., 1988, 1990, 1992, Oliver, 1993). The Hadza hunt and scavenge a variety of large and small mammals on foot using bows and arrows, which are usually tipped with poison. Hadza employ encounter hunting, which is essentially dependent on random encounters with animals, and intercept hunting, where prey is stalked or waited for at a hunting blind. These hunting blinds are commonly used during the dry season, and placed near watering holes or game trails. The Hadza also field-butcher their kills, and consume some choice parts such as marrow from defleshed bones and head contents at the butchery site. Often, large animals must be tracked for a few hours before they succumb to the poison, but when an animal dies near the hunting blind, it is usually butchered and snacked upon there. Carcass transport decisions are based on distance to the base camp, ease of stripping specific elements, time and water constraints, and the number of helpers. Ultimately the net return of useful animal tissue is weighed in light of the costs to process in the field and transport (O’Connell et al., 1988). This translates into the abandonment of limb bones, especially defleshed and de-marrowed lower limbs,
along with other limbs, skulls, mandibles and ribs, at kill or initial butchery sites, and transport of vertebrae, pelves and scapulae for further processing at base camps.

Bunn (2001) describes the patterning of cut marks on Hadza bone assemblages in terms of anatomical location. In short, he finds an abundance of cut marks on upper limb elements, particularly on the femur, and these marks are distributed over all of the bones in concentrations near the proximal and distal ends.

With these basic patterns of Nunamiut and Hadza faunal interaction described, we can investigate whether these observations are appropriate analogs with which to evaluate hominin archaeological bone modification.

The major problem with applying Nunamiut and Hadza models to Plio-Pleistocene hominins arises from the differences in the behavior and ecology of modern hunter-gatherers, and those inferred for Plio-Pleistocene hominins (Schrire, 1984). This re-emphasizes Gifford-Gonzalez’s (1991) caution against transferred ecology. Certainly hominins did not live in near-Arctic environments or ride snowmobiles, so the contingencies affecting Nunamiut transport are inappropriate analogs for linking the static traces of hominin behavior with unknown, but surely dissimilar higher-range contexts. Butchery and transport decisions embedded within the Nunamiut behavior of long-term meat storage, also call this analog into question.

Likewise, the Hadza may be an inappropriate analog, although their ecological context is closer to hominins living in Plio-Pleistocene Africa in terms of the general wooded savanna ecological setting. The Hadza use poisoned arrows, a technological development not thought to have originated until recent times. In addition, it may be wholly inappropriate to apply ethnoarchaeological data from hunter-gatherers, when the
existence of hominin hunting is not established (e.g. Binford, 1981, Blumenschine, 1988, Dominguez-Rodrigo, 2002 etc.).

On the other hand, can we use Yellen’s (1977) general approach for ethnoarchaeological data to highlight any common patterns of human-carcass interaction? The Hadza and Nunamiut ethnoarchaeologies both document transport and butchery decisions that are based on the costs and benefits of transport and the amount and quality of animal resources that are generally related to the distance from camp and the mode of transport. It seems that these ethnoarchaeological observations support the basic predictions of optimal foraging theory, a result that may not be groundbreaking, but establishes a very general relational analogy between static traces (patterned faunal remains) and higher-range behavioral and ecological contexts (transport decisions that optimize costs and benefits of a set of parameters).

Using Gifford-Gonzalez’s hierarchy of relational analogies

Most analyses of hominin behavior employ the actualistic or ethnoarchaeological results described above to create analogies, which ground higher-range behavioral and ecological extensions of static traces with modern analogs. As described above, each of these methods has advantages and flaws, but the demonstration that the analog used, either actualistic results or ethnoarchaeological observations, is an accurate model of the inferred past is the crux of this issue.

With this said, it is interesting to discuss the analyses of the FLK *Zinjanthropus* assemblage from Bed I at Olduvai Gorge, examining the middle-range methods that
generate behavioral and ecological contexts for zooarchaeological data. This assemblage has probably generated the most debate about Pliocene hominin carnivory, and the hominin activity that generated the assemblage has been interpreted in many alternate, if not opposite ways.

The FLK Zinj assemblage has around 60,000 specimens, with 3500 larger mammal bone fragments, a minimum number of individuals of 48, with more than half coming from small and medium-sized animals, and a predominance of head and limb parts at the expense of scapulae, pelves and vertebrae (Bunn and Kroll, 1986). Around 66% of long bone specimens have carnivore tooth marks, and 19% have cut marks, which are more common on epiphyseal portions, than on near-epiphyses or midshafts (Bunn and Kroll, 1986).

Regarding skeletal part profiles, the early analysis of Bunn and Kroll (1986) describes systematic butchery by hominins at the Zinj site, where the patterns in element representation described above are taken as evidence of a hominin behavioral strategy that involved transport of meaty elements. This does not truly qualify as middle-range research, rather it is a post-hoc explanatory argument (or an assertion of the schlep effect’s operation) designed to coincide with archaeologically observed patters. Similar to Brain’s criticisms of Dart’s osteodontokeratic, the demonstration that bone destroying hyenas will remove precisely the parts missing from the Zinj assemblage when ravaging a discarded, hammerstone-fragmented bone assemblage (Brain, 1981, Marean et al., 1992, Blumenschine and Marean, 1993) falsifies Bunn and Kroll’s (1986) argument. This highlights the persistence of an equifinality regarding the elements and portions hominins potentially introduced to a site, and the preference of bone consumers to delete the least
dense, greasiest or most nutritious portions that they encounter, regardless of completeness or skeletal part and portion representation. The lack of a deductive investigation into the processes acting during the taphonomic history of the Zinj assemblage makes it difficult to determine if hominins did not transport specific elements to FLK Zinj, or if hyenas selectively destroyed limbs, epiphyses, and axial elements.

The next group of analyses is informed by the actualistic results modeling different hominin and carnivore access sequences (Blumenschine, 1995, Capaldo, 1997, Dominguez-Rodrigo, 1997, Selvaggio, 1994). These studies benefit from the empirical links between different classes of bone modification and their agents that a taphonomic perspective advocates (Bunn, 1981, Blumenschine and Selvaggio, 1988, etc.). The generation of multiple hypotheses of hominin carcass access, and their analogous modern modification pattern, allows these investigations to proceed in a scientific manner. Unfortunately, not all of the investigators generated similar or even comparable actualistic results, explaining in part why their conclusions differ. For example, Blumenschine (1995) suggests that the modified fauna at FLK Zinj supports hominin access to defleshed carcasses that were fragmented for marrow by hominins, and subsequently ravaged by hyenas. Capaldo’s (1997) work, which investigated tooth marks as well as cut marks, found the occurrence of cut marks on some midshaft specimens, along with frequent tooth marks on midshafts. Selvaggio’s (1994) analysis yielded similar results as well. The frequency of modification in the Zinj assemblage matches with Selvaggio’s secondary hominin access to defleshed carcasses scenario. Her actualistic results also support the idea that hominins could have accessed carcasses with flesh scraps if a single carnivore or small group generated the carcass. In contrast to this,
Dominguez-Rodrigo (1997) concludes that the hominins responsible for generating the FLK Zinj assemblage had access to meaty carcasses, suggested by the similarity of actualistic and archaeological cut mark patterning on the upper limb bones, thought to be meatier, requiring more cuts (and unintentional cut marks) to remove meat.

How can these diverse results derive from generally similar actualistic experiments, and from analyses of the same archaeofauna? Inter-analyst variation in experimental design, specifically actualistic protocol, and the interpretation of archaeological bone modification are probably major factors (Dominguez-Rodrigo, 2002 Lupo and O’Connell, 2002). Before addressing these issues, another example of the use of middle-range research to understand hominin bone modification at FLK Zinj should be described.

Bunn (2001) returns to re-analyze the role of hominins in the FLK Zinj assemblage, but this time, adopting a specifically ethnoarchaeological approach, applying data from Hadza cut-marking during butchery. Bunn (2001) also employs the meaty/lean, upper/lower limb dichotomy used by Dominguez-Rodrigo (1997, 1999, 2001, 2003). The patterning of cut marks on the meaty upper limb elements, and generally around epiphyses and near-epiphyses in Hadza assemblages, where all carcasses were fully fleshed, is argued to match the FLK Zinj pattern of cut mark location with respect to element and skeletal portion. Additionally, Bunn (2001) argues that the increased number of cut marks on the humerus as opposed to the femur indicates the strength of the muscle attachment since both of these elements hold similar amounts of meat, and discounts differential access to these skeletal portions related to scavenging.
Two interpretations emerge from the analysis of hominin butchery and carcass consumption in the FLK Zinj assemblage: hominins accessing defleshed carcasses and exploiting marrow, and hominins accessing meaty carcasses, and presumably also exploiting marrow. The Zinj debate indicates that zooarchaeological analyses ultimately seek the higher-range behavioral and ecological contexts outlined by Gifford-Gonzalez, and that their interpretations vary tremendously based on the analytical technique employed. However, I suggest that these analyses fail to conclusively link the low and high-ranges because certain equifinalities amongst behavioral contexts have not yet been broken.

Specifically, these analyses do not attempt to distinguish cut marks created during different butchery actions like skinning, disarticualtion and defleshing. Ultimately, most of these analyses collapse all cut-marked bones into a general category that limits the possibility of interpreting distinct butchery actions in the assemblage. Further, it is difficult to interpret butchery behavior in the Zinj assemblage because analysis of modified bones is not conducted on a scale that is relevant to hominin butchery of individual animals or parts of their carcasses. Modified bone specimens are excavated and interpreted by zooarchaeologists, but hominins butchered whole elements, limbs or complete animals. The following chapters in this dissertation attempt to solidify the links between cut mark traces on different parts of the skeleton and the butchery actions they represent, and develop secure ways to interpret ancient butchery in zooarchaeological assemblages that are comprised of bone fragments. These techniques are used to provide a more robust test of previous interpretations of the butchery behaviors recorded in three
Okote Member (1.4-1.6 Ma) assemblages at Koobi Fora (Pobiner, 2007, Pobiner et al., 2008), and ultimately infer the ecological mode of *Homo erectus*’ carcass access.

**Conclusion**

The proceeding discussion of actualistic and ethnoarchaeological techniques for establishing present-day process-trace relationships, and their use in the analysis of the archaeofaunal remains from the FLK Zinj site demonstrate the current state of zooarchaeological analysis of Plio-Pleistocene hominin behavior. Taphonomy as a theoretical body existed in paleontology for decades before it was adopted by East African zooarchaeologists in the midst of a transition from a culture historic approach, to a processual approach interested in understanding site formation in general (Behrensmeyer and Dechant Boaz, 1980, Binford, 1981, Efremov, 1940).

The taphonomic perspective emphasized the scientific method, which for zooarchaeologists meant testing hypotheses of non-hominin involvement in the patterning of faunal assemblages. This necessitated the connection of assemblage-wide patterns or modifications to individual specimens to the means by which they were created. This would not have been possible without the detailed modeling of a general taphonomic history and a theoretical means to connect static traces of past activities to the operation of ancient complex systems (Behrensmeyer and Kidwell, 1986, Binford, 1981, Gifford-Gonzalez, 1991).

The nested hierarchy of relational analogies developed by Gifford-Gonzalez (1991) is the framework that guides zooarchaeological interpretation. But even its
usefulness breaks down at the highest levels of inference. There is an unclear boundary between Gifford-Gonzalez’s behavioral context and the social and ecological context. In fact the highest level includes both the social and ecological contexts in one hierarchical category, a relationship that calls for revision (see a more thorough discussion in Chapter 4).

Regardless of this confusion, the application of these methods has connected zooarchaeological remains to the stone tools and hominins that made them, in a context of carnivory. Connecting the low and middle-range relationship to the operation of high-range processes has not been entirely successful to date. Actualism and ethnoarchaeology address high range processes like behavior and ecology, but problems exist with creating completely appropriate analogs using these methods. In part, this difficulty may relate the blurry definitions of Gifford-Gonzalez’s (1991) high range contexts, but more importantly how these contexts can be investigated using zooarchaeological data and contemporary investigations.

The results of any archaeological research must rely in the end on the archaeological record, whether its structure is acceptable or a hindrance (Isaac and Crader, 1981, Isaac, 1983). Perhaps the higher-range contexts of the nested hierarchy should be reorganized to take better advantage of the faunal record. Likewise, the most reliable methods of connecting contexts with traces, actualism and ethnoarchaeology, should generate results which can be used directly within Gifford-Gonzalez’s hierarchy. However, maybe the hierarchy should proceed from the actor to the behavioral ecological context, to the paleoecological context. Interpreting the paleoecological context views hominin behavior in light of selection pressures introduced by the environment
(Behrensmeyer and Kidwell, 1985, Behrensmeyer, 2000, Foley, 1994) and would be the next logical step, but at what point does the evidence necessary to reach these broad conclusions cease to exist? This introductory chapter suggests that the interpretive trajectory from the static traces to interpretations about ancient carnivory is blurred at the level of the behavioral context. The work presented in this dissertation attempts to resolve the inferential connection between distinct contexts of butchery behavior and their traces on the skeleton and define a strategy for detecting this behavior in fragmentary zooarchaeological assemblages.
Chapter 2. Experimental butchery factors’ influence on cut mark cross-sectional size: implications for Early Stone Age carnivory

Abstract

This set of experiments investigates the stone tool characteristics and contextual butchery factors that influence cut mark width and depth, measured from cross-sections of bone surface molds, to test whether cut mark size is useful in inferring tool identity. A pastoralist experienced in stone tool butchery used replicated Oldowan flake and bifacial core tools in experimental trials that isolated skinning, bulk and scrap muscle defleshing and element disarticulation cut marks on goat and cow skeletons. This large experimental sample explores the cut mark traces generated under realistic butchery scenarios and suggests the following results: core tools were significantly heavier and had more obtuse edges than flake tools, but both tool classes were equally efficient at completing all butchery tasks in goats and cows. Distributions of flake and core cut mark width and depth in the total sample could not be distinguished, but skinning and disarticulation produced significantly wider and deeper marks than defleshing. Cut marks on cows tended to be wider and deeper than those on goats. When the sample of experimental cut marks was stratified to remove the confounding influence of butchery action, carcass size and bone portion on cut mark cross section, tool weight had a strong, positive correlation with average defleshing cut mark width only in the cow sample. Cut mark size is similar on elements butchered early and late in the butchery sequence. Bone portion density is negatively associated with cut mark width per portion in both size classes. Because the numerous butchery contingencies affecting cut mark size on archaeological specimens
are further blurred by taphonomic process that destroy bones or decrease skeletal element identifiability, a general quantitative model for predicting tool type or edge characteristics from cut mark size is not warranted. Instead, these experiments suggest that cut mark width and depth are useful for distinguishing defleshing marks from disarticulation which are known to co-occur on certain limb bone joint portions. Cut mark size adds another contextual line of evidence that eliminates equifinality between butchery actions representing early or late access to carcass resources.

Introduction

Like no other class of archaeological evidence, butchered bone records the intersection of tool use and the feeding behavior of early humans, offering a glimpse at the evolution of our lineage’s use of technology to mediate selection pressures. Pioneering Early Stone Age archaeologists interpreted the function of Oldowan stone artifacts as butchery tools because their spatial association with faunal remains was assumed to represent a behavioral connection (Leakey, 1971, Shipman et al., 1981). In questioning these assumptions, the emerging field of taphonomy suggested that faunal preservation may occur independently of human behavior (Binford, 1981, Lyman, 1994, Potts, 1988), and used experimental studies of modern analogs to establish diagnostic criteria that identified whether bone specimens were butchered, consumed by carnivores, or trampled (Andrews and Cook, 1985, Behrensmeyer, 1978, Behrensmeyer et al., 1986, Blumenschine and Selvaggio, 1988, Brain, 1981, Bunn, 1981, Njau and Blumenschine, 2006, Olsen and Shipman, 1988, Potts and Shipman, 1981). Seminal works by Bunn (1981) and Potts and Shipman (1981) expanded on the earliest butchery experiments
(Walker and Long, 1977) to demonstrate that linear v-shaped striations were incised in cortical bone during stone tool butchery, and that these marks matched Early Pleistocene bone specimens from Koobi Fora and Olduvai Gorge.

Around the same time, butchery replication trials were undertaken to better understand Oldowan typology and tool function, reporting on the efficiency of different core forms for butchery tasks and attempting to resolve whether flakes were by-products of core manufacture or useful tools in their own right (Jones, 1980, Toth, 1985). Jones suggested that core tools are heavier and easier to hold, and are therefore better suited to all butchery tasks, especially processing large animal carcasses. In contrast, Toth’s observations suggested that Oldowan core types represented different moments during the sequence of flake removal, and while cores were useful in defleshing large animals, the straight, sharp edge of a flake was as efficient for defleshing and functioned better in activities like skinning and disarticulation. Toth suggested that flakes produced isolated cut marks and cores produced scatters of marks with less-parallel orientation, but neither study carefully defined zooarchaeological signatures of butchery that could identify whether flakes or different types of cores were used to process carcasses.

Walker and Long (1977) conducted the earliest butchery experiment that quantified cut marks made by flakes and bifacial core tools. Although their work focused on comparing cut marks made with pressure flaked bifacial points to unmodified flake tool marks in the North American Holocene, they demonstrated a general phenomenon that re-occurs in most experimental and archaeological investigations that aim to link cut mark morphology and tool attributes: core tools produce cut marks with a wide and shallow cross-section, whereas flake tools produce deep and narrow cut marks. Recent
investigations using optical microscopy, scanning electron microscopy (SEM) and 3D visualization quantify the cross-sectional morphology of experimentally generated cut marks made by different classes of butchery tools, including bamboo, shell, metal knives, and stone flakes, cores, handaxes and scrapers (Bello and Soligo, 2007, Bello et al., 2009, Choi and Driwantoro, 2007, see also Toth and Woods, 1989, Greenfield, 1999, 2006, West and Louys, 2007). These studies describe typical core or retouched tool mark as wide and shallow, unmodified flake or blade marks as narrow and deep with fewer steps in the mark’s walls, and indicate that a tool’s edge angle is positively related to cut mark width.

However, methodological shortcomings highlight the impracticality of archaeological interpretations of tool use from cut mark cross-section. Walker and Long’s (1977) groundbreaking study quantified cut mark width and depth on defleshed cow metapodials made by a single tool from five or fewer marks at three slicing pressures. Greenfield (1999, 2006) qualitatively described the cross-sectional shape of one cut mark incised into a pine board or defleshed animal bone with a single metal knife, stone flake or retouched core tool. Bello and Soligo (2007) used 3D scanning to quantify wall profile geometry of one stone flake cut mark made on a defleshed pig rib for each of three hand positions at seven points along the mark. Shipman and Rose (1983) measured a sample of 70 cut marks produced by a flint tool with an edge angle ranging between 78 to 90 degrees on a defleshed innominate and ribs. They compared the first and 260th cut mark produced by this tool, finding little variation in cross-sectional morphology as the edge dulled, leading them to conclude that cut mark morphology can be used to identify tool edge angle. While these experiments aim to establish representative cut mark
morphologies for different tool classes, their small samples of cut marks do not document the variance in morphology created by flakes versus cores. Experiments that use a single tool to slice a defleshed bone do not model how cut mark morphology is affected by numerous contingencies during carcass processing and consumption, including the butchery action performed, the bone portion where cut marks occur, or animal size class. The differences in hand angle and tool pressure necessary to accomplish different butchery tasks like skinning versus defleshing are also likely to affect cut mark width and depth (Bello and Soligo, 2007).

Here, I describe a series of experimental butchery trials conducted to document whether cores are more efficient butchery tools than flakes, and to explore the factors that contribute to differences in cut mark width and depth. If cores allow quicker carcass processing, their use would offer a competitive advantage to the user, and if experimental flake and core cut marks have easily distinguishable cross-sectional size, their use may be detected reliably in the archaeological record. The results allow an assessment of how well the cross-sectional morphology of cut marks made by different classes of stone tools can be used to interpret Early Stone Age butchery behavior.

Materials and Methods

Experimental design

This set of experiments investigates the stone tool characteristics and contextual butchery factors that influence cut mark cross-sectional size, with the ultimate goal of quantifying flake versus core cut mark size. Butchery trials consist of half-carcass replications of fore- and hindlimb musculo-skeletal units without phalanges. Cut marks
made by different tools are examined across butchery action (skinning, element
disarticulation, bulk muscle defleshing, scrap muscle defleshing), carcass size
(mammalian size class 1 and 3) and long bone portion (proximal epiphysis, proximal
near-epiphysis, midshaft, distal near-epiphysis and distal epiphysis) categories. The
sample of 32 butchery trials follows a full factorial design with two half-carcass
replications of each, tool type/action/size treatment (Table 2-1).

Experimental Butchery Procedure

A Dassenech man experienced in livestock butchery conducted all experimental
trials to eliminate individual variability in cut mark production and gather data about one
butcher’s tool preferences for accomplishing different tasks on large and small animals.
The butcher was offered a choice of replicated Oldowan unmodified cortical and non-
cortical flakes and bifacially flaked cores made from raw materials that also occur in
Early Pleistocene archaeological deposits at Koobi Fora. He was asked to select a flake or
core which best suited the task, and to perform each butchery action as efficiently as
possible, removing the largest amount of flesh with fewest strokes or making the most
effective cuts to disarticulate a joint. The butcher was naïve about the analysis of cut
mark size. Tools were never retouched during butchery and in most cases a single tool
was used on both the fore- and hindlimb of a half-carcass trial. Butchery trials were
recorded on video and timed to the nearest minute.

Tool edge angle was measured with a goniometer at the most obtuse point along
the cutting edge and tool weight was measured to the nearest tenth of a gram with a
digital scale. In four pilot butchery trials included in this study, tools were not retained
and edge angle was not recorded. An analysis of variance of tool edge angle across treatment groups shows that as expected, average flake and core edge angle is significantly different, but highlights other experimental biases whose influence on cut mark size must be accounted for (Table 2-2). A multiple comparison procedure indicates that on average, cows were butchered with wider tools than goats, and skinning trials used wider tools than bulk defleshing trials. Figure 2-1 shows the edge angle distributions across treatment groups. A non-parametric Kruskal-Wallis test confirms that cores have significantly wider edges than flakes but does not find significantly different median edges between other treatment categories. Tool weight is more evenly distributed across treatment groups; cores are significantly heavier than flakes but animal size class and butchery action categories were butchered with tools of similar weight (Table 2-3, Figure 2-2). The following analysis of cut mark size stratifies the sample across carcass size and butchery action categories to control the experimental bias in edge angle where cows were butchered with wider tools on average than goats.

To examine how cut mark morphology varies with butchery action, distinct actions were replicated in different trials, and each action targeted a mutually exclusive set of soft-tissues. Skinning included transverse slices around the distal near-epiphyses of the metapodials, and medial incisions running superiorly up each leg (Figure 2-3). In a pilot study, contact between the stone tool and bone during skinning was limited to the transverse incision that severed the hide and cut through subcutaneous tissue into the bone surface. Because of this, after the initial skinning incision, the remainder of skin removal was completed with a metal knife and the hands. The time recorded for skinning trials represents only the transverse incision made with stone tools.
Disarticulation trials investigate cut marks produced by disarticulating limb elements, excluding the phalanges. Preparation for disarticulation trails involved flesh removal with a metal knife, which left a small amount of muscle tissue surrounding the joints. This process was video-recorded to ensure any metal knife preparation marks were removed from cut mark analysis.

Bulk muscle defleshing targeted the large muscle groups of the fore- and hindlimbs including the scapula, innominate and lumbar vertebrae. The metapodials and phalanges were not defleshed since they are encased in tendon. The butcher was asked to remove as much flesh as necessary, without disarticulating the bones, to expose the majority of the bone shaft so that fragmentation with a hammerstone and anvil would be possible. The periosteum was not removed. Typically, this resulted in remnants of adhering flesh around joints and at some muscle attachment sites.

Muscle scrap defleshing targeted deep muscles surrounding joints and the small scraps of flesh remaining near their skeletal or tendonous attachment sites on fore- and hindlimbs, excluding the metapodials or phalanges. Scrap defleshing targeted flesh that remained after bulk defleshing, but these trials were conducted separately (Figures 2-4 to 2-7). Goat and cow limbs typically yielded between 250 to 500, and 500 to 1000 grams of muscle scraps respectively, which were concentrated on the scapula, innominate, and around joint capsules. Bulk muscles were removed carefully with a metal knife and this process was observed closely and video-recorded to exclude metal knife preparation marks from analysis.

Bone Specimen Preparation
Bones were boiled for 4-8 hours in saline-alkaline lake water, and adhering soft tissue was removed by hand. A second boil in an approximately 1:1000 solution of hydrogen peroxide and water for 4-8 hours was conducted after two holes approximately two millimeters in size were drilled into long bones’ medulary cavities to aid degreasing. Trials requiring additional degreasing were boiled for a third or fourth session under the same conditions. Bones were air-dried after boiling and were considered degreased when fatty residues no longer covered the dry bone surface.

Experimental cut mark identification, molding and measurement

Each element was examined under strong, low-incidence light from at least two directions using a 10x handlens to identify cut marks (Blumenschine et al., 1996, Bunn, 1981, Potts and Shipman, 1981). Cut mark location was recorded on a bone portion scale for each limb element, which also described the anatomical direction on the bone shaft (anterior, medial, posterior, lateral) and distinguished between cortical and non-cortical sections of the epiphyses. Bone portions were defined following Blumenschine (1995) and Lyman (1994), where proximal epiphyses (PEPI) and distal epiphyses (DEPI) contain articular and non-articular cortical bone and are bounded by the metaphysis. Proximal near-epiphyses (PNEF) and distal near-epiphyses (DNEF) contain cancellous medullary surfaces, and were defined as the area from the metaphysis to the beginning of the midshaft diameter. These portions typically include muscle attachment sites like the deltoid and radial tuberosities, lesser trochanter and the tibial crest, and in sub-adult domesticates may possess a roughened cortical texture, particularly in DNEF. Midshaft
(MSH) portions occur between PNEF and DNEF portions and have smooth cortical bone and medullary surfaces.

The area surrounding a cut mark was searched carefully to establish the boundaries of the cut mark cluster, which was circled in pencil. Each cluster of cut marks was drawn, and each mark was given a number. A cluster of slices is counted as a single cut mark by some authors (e.g. Johnson and Bement, 2009, Lyman, 2005), but this study counts each distinct slice with a clear origin and termination as a single cut mark.

Cut mark clusters were molded with 3M Express Bite Registration putty. With reference to the bone and cluster drawing, each numbered mark was identified on the mold and cross-sectioned by hand at its widest point using a razor. Cross-sectioning a cut mark mold allows measurement of the negative shape of the mark’s depth, a process accomplished with a binocular microscope at 32x magnification with a micrometer disc precise to 0.03125mm. Width, defined as the distance across the incision into the cortical surface, and depth, defined as the perpendicular distance from the cortical surface to the mark’s floor, were recorded (Figure 2-8). Every cut mark was molded and measured. In a test of reproducibility only 6.9% of 72 width and depth measurements differed by more than 0.09 millimeters from their initial value. Compared to SEM micrographs or 3D scans, measurement of cut mark size from vinyl polysiloxane molds is less precise, but this method allows a much greater number of cut marks to be measured at a relatively low cost.

Hypotheses tested
Time per trial will be used to test the null hypothesis that flakes and cores are equally effective butchery tools in animal size class and butchery action categories. If cores are more efficient for large animal butchery, core trials should be completed more quickly in cows and flake trials should be completed more quickly in goats.

It is hypothesized that variability in cut mark size introduced by animal size class, bone portion, and butchery action may mask differences in flake and core cut mark size, but when the effects of these confounding factors are controlled, any differences in cut mark size caused by tool type will be exposed. Flakes are predicted to make narrower and deeper cut marks compared to cores since they have more acute cutting edges with flake scars only on the dorsal surface, whereas cores have wider edges and bifacial flake scars (Bunn, 1994, Walker and Long, 1977). On a finer scale, tool edge angle is predicted to correlate positively with cut mark width and negatively with cut mark depth. Tool weight is expected to correlate positively with cut mark width and depth. These associations are expected when all tools are considered together as well as within flake and core categories.

Animal size class is not predicted to influence cut mark size since both goats and cows have similar musculo-skeletal anatomy. For cow and goat samples, it is predicted that cut mark size distributions will be indistinguishable and average cut mark width per bone portion will be positively correlated.

Skinning and disarticulation are expected to generate cut marks that are wider and deeper since they require greater cutting force typically at perpendicular angles to the bone surface, whereas bulk and scrap defleshing are expected to make shallower and
narrower cut marks since filleting muscles or severing tendinous muscle terminations require less force and a more oblique cutting angle (Nilssen, 2000).

A cut mark’s skeletal location may influence its cross-sectional size since cutting into bone of lower density or rougher surface texture is predicted to make wider and deeper cut marks. Cut marks on midshafts (MSH) are predicted to be narrower and shallower than cut marks on less-dense near-epiphyses (NEF) and epiphyseal (EPI) portions. This is explored in bulk and scrap defleshing butchery trials to minimize the confounding effect of skinning and disarticulation, which are hypothesized to make wide and deep cut marks that occur predominantly on EPI and NEF portions. Bone density values taken from *Connochetes taurinus* (Lam et al., 1999) are predicted to correlate negatively with average defleshing cut mark width per portion in goats and cows.

If tool sharpness affects cut mark size, average cut mark width and depth are predicted to decrease as a tool dulls during the sequence of carcass segment butchery. This relationship is examined in defleshing trials on a sample of cow long bone shafts and dense innominate portions where the order of forelimb, hindlimb and innominate butchery was experimentally manipulated.

**Results**

*Flake versus core butchery time*

No significant differences exist between flake and core butchery trial time when a paired t-test is used to compare flake and core trials across animal size class and all butchery actions ($t = 0.075, p = 0.941$). This result is supported by the Wilcoxon Rank
Sum test (Z = 0.189, p = 0.850). A two-way ANOVA with interaction effects that examines flake and core defleshing trial time across carcass size and tool type categories finds that cows took significantly longer to deflesh, but neither tool type was quicker in the entire sample, or in goat or cow trials (Table 2-4). These data are not distributed normally, but both ANOVA on logarithmically transformed time and the non-parametric Kruskal-Wallis test on untransformed data find significant butchery time differences only between goat and cow samples.

**Cut mark size differences across single-factor categories**

When all cut marks are examined, the median cut marks made by flakes and cores are equal in width and their right-skewed distributions are nearly identical (Figure 2-9). The median core cut mark’s depth is significantly deeper than the median flake mark, but the interquartile ranges of both tools’ marks overlap completely (Figure 2-10). These similarities are intriguing in light of the significantly wider edges and heavier mass of core tools compared with flakes. The median cut mark in the cow sample is significantly wider than the median goat cut mark, and the range of cow marks includes higher values than the goat sample. The cow sample has a significantly deeper median mark, although their ranges overlap almost completely. Cows tended to be butchered with wider-edged tools on average, so this difference may result from treatment bias. Stratifying the sample of cut marks into goat and cow sub-samples will expose this effect.

In the entire sample, skinning and disarticulation marks have equivalent median width and depth and are significantly wider and deeper than the median bulk and scrap defleshing marks. The median bulk and scrap defleshing marks are equivalent with
respect to width but have different median depths and an equivalent interquartile range. Skinning and disarticulation marks tend to be wider and deeper than defleshing marks despite similarity in tool edge angle and weight across butchery action categories. However, skinning trials were carried out with wider-edged tools than bulk defleshing trials on average, so stratifying the sample to separate defleshing from skinning and disarticulation will ensure that the difference in edge angle across butchery action categories does not confound the analysis of cut mark size.

Analyses of variance for average cut mark width and depth per tool were carried out across carcass size, butchery action and tool type categories with 2-factor interaction (Table 2-5). Average cut mark width and depth per tool were logarithmically transformed to bring their samples closer to normality, and although the Lilliefors test indicates neither log average width or depth per trial is normally distributed, skewness and kurtosis are near the normal range (s = 0.248, 0.22, k = 1.595, 1.797 for log average width and depth respectively). Cow trials had significantly deeper and wider log average cut mark values than goat trials. Skinning and disarticulation trials both had significantly wider and deeper average cut marks than bulk and scrap defleshing cut marks. No significant differences were detected between the average width and depth of core and flake trials. Likewise, differences between the average size of flake and core marks were not detected across butchery action or carcass size categories. The Kruskal-Wallis test corroborates the significantly wider and deeper cut marks made during skinning and disarticulation, compared to defleshing, however, it does not find significantly larger cut marks in the cow sample.
Cut mark size across bone portions of different density

In addition to tool edge characteristics, cut mark size may be affected by differences in the hardness of the bone surface underlying the tissues being butchered. Since disarticulation targets only epiphyseal bone portions, and skinning introduces marks only onto the distal near-epiphyses of metapodials, and cut marks made in these trials are known to be wider and deeper than marks made during flesh removal, defleshing trials are examined to further investigate whether tool edge angle and weight affect cut mark width and depth.

When all defleshing marks on long bones are considered, the median MSH mark is significantly narrower than the median NEF and EPI marks (Figure 2-11). Cut mark depth occupies a much narrower range of values, but the median MSH and PNEF are equivalent and shallower than the median DNEF and EPI cut marks (Figure 2-12). This result suggests that per-portion bone density affects cut mark size.

Lam et al. (1999) present bone mineral density (BMD) data for different anatomical regions of the Connochaetes taurinus skeleton that are used to examine the relationship between mean cut mark width and bone density per portion in the goat and cow samples (Table 2-6). When the scapula and innominate are included, the goat sample shows a significant negative rank-order correlation between per-portion cut mark width and BMD (Spearman’s r = -0.547, p = 0.003), although the cow sample does not (Spearman’s r = -0.233, p = 0.224). When only long bone portions are considered, both cow and goat samples show significant negative rank-order correlations between average mark width and BMD (Spearman’s r = -0.475, p = 0.047; r = -0.613, p = 0.009). This result indicates that in general, cut marks tend to be wider on less dense bones.
Interestingly, average surface width per portion does not correlate strongly between cow and goat samples for all portions or only in long bones, (Pearson’s $r = 0.131$, $p = 0.525$; $r = 0.250$, $p = 0.331$). Since *C. taurinus* BMD values were used for both goats and cows, and these closely related taxa are assumed to have similar per-portion density values across the skeleton, factors other than density may influence cut mark width.

*Cut mark size differences per tool*

Grouping the cut marks made by different flake or core tools into a single distribution may not expose the relationship between tool variables and cut mark size. Plotting mark width and depth against tool edge angle and shows the relationship between tool characteristics and cut mark cross-sectional size more clearly. Although cut mark distributions tend to be right-skewed and kurtotic, mean cut mark width and depth are calculated per tool, a procedure considered appropriate since cut mark sample size is large in defleshing trials, and the greater width and depth of skinning and disarticulation marks is confirmed by the Kruskal-Wallis test.

Scatter plots show the untransformed relationship between tool edge angle and weight against average cut mark width and depth per tool, stratified into carcass size and tool type categories (Figure 2-13). For both the goat and cow samples, skinning and disarticulation marks tend to produce wider and deeper average marks at the same edge angle or tool weight compared to defleshing marks. Within these action and carcass size categories, no clear pattern emerges to suggest a strong relationship between cut mark size and tool variables. Most of the tool weight values are clustered between 0-200 grams with a fewer heavier tools, suggesting a non-normal distribution.
Correlation analyses were carried out in sub-samples stratified across carcass size and butchery action categories that distinguish skinning and disarticulation trials from MSH cut marks in defleshing trials. Lilliefors tests indicate that tool attributes and average cut mark size values are distributed normally within all sub-samples once logarithmic transformation of tool weight reduces their skewness and kurtosis.

No strong or significant correlations between tool edge angle or weight and average cut mark width or depth occur in the skinning and disarticulation sub-sample (Figure 2-14, Table 2-7). In the defleshing sub-sample, average MSH cut mark width is positively correlated with log tool weight in cow trials, although this relationship does not occur in the goat sample (Figure 2-15, Table 2-7). With such loose relationships between tool attributes and average cut mark size, regression analysis cannot explain a large proportion of variance in cut mark dimensions, limiting inferences about tool edge angle or weight from cut mark size.

Cut mark size through the butchery sequence

During different cow defleshing trials the order in which the forelimb, hindlimb and each half of the pelvis was experimentally varied to examine the effect of a duller tool edge on cut mark cross-section (Table 2-8). Only marks on limb bone shafts and the denser innominate portions including the iliac, pubic and ischial rami were examined to minimize the bone density differences. In all cow trials, median cut mark width and depth do not differ across these carcass segments (Figure 2-16). Distributions of cut mark size are nearly identical despite whether they occurred early or late in the butchery sequence (Figure 2-17).
Some trials included in the butchery sequence investigation included long pauses during the butchery process. Typically one half-carcass trial was conducted early in the day, and the other half was conducted after the butcher rested, ate and attended to the other social obligations that occur when animals are butchered in a pastoralist community. The average of log transformed cut mark width and depth per carcass segment does not correlate strongly with post-mortem time, indicating that cut mark cross-sectional size is not significantly affected by the onset of rigor mortis (Table 2-9).

**Discrimination of flake and core tool marks in a stratified sample**

Discriminant analysis (DA), distinguishes samples representing categories of observations, and is employed to test the reliability of flake and core tool diagnosis using cut mark cross-sectional size. Cow and goat cut marks were considered separately, and midshaft portions were examined in defleshing trials to minimize confounding effects on cut mark size introduced by different butchery actions or bone density per portion. Boxplots show that across carcass size and tool type categories in cows, cores and flake MSH defleshing marks have an equivalent median width, but wider marks tend to be made by core tools (Figure 2-18). In the goat sample, cores produced a significantly wider median mark. Mark depth occupies a much narrower range of values, and size-tool samples are right skewed and kurtotic (Figure 2-19). These boxplots indicate that cut mark samples are non-normally distributed, and to come closer to the multivariate normality assumption of linear discriminant analysis, samples of cut mark width and depth are log-transformed. Although this transformation does not produce normal samples, the large number of marks helps offset the effect of outlying values. DA uses
log cut mark width and depth to define the multivariate boundaries of cut mark size for the size-tool samples, and then classifies marks into the appropriate category (Table 2-10). In the cow sample 45% of marks were misclassified with respect to the correct tool type, and 49% of marks were misclassified in the goat sample. Classification success is virtually identical when log-width is used alone or when log-width and log-depth are used together to define the boundaries of flake and core cut mark size. This result shows that a large degree of overlap in cut mark width and depth makes it impossible to identify tool type from cut mark size, and that using width and depth together does not improve tool type discrimination.

Discussion

Tool efficiency

Comparing flake and core trials on the same butchery action and animal size class shows that both tools were similarly effective at processing large and small animals, making incisions in skin, defleshing, and disarticulating bones. In light of this similarity, differences in the edge angle and weight of the tools selected for different trials reflect the tool attributes considered preferable by an experienced butcher. As a member of the Dassenech tribe living in a sub-desert area of Northern Kenya with limited access to modern supplies, the experimental butcher reported some experience with lithic tool butchery, breaking chert rocks for use as expedient tools when small animals were encountered and metal knives were not available. Heavier tools and those with wider, more robust edges were preferred for skinning trials and for processing cows. This result
fits with both Jones’ (1980) and Toth’s (1985) findings that while flakes were suitable for nearly any task, more robust tools made large animal butchery feel easier.

When tools dulled during butchery they were not retouched; only adhering fat was removed, which refreshed the edge’s sharpness. However, cut mark size does not change significantly during a tool’s use life. In real butchery episodes we expect that a tool retouch versus abandonment decision is linked to a raw material conservation plan (Andrefsky, 1994), but there is no basis to expect that cut mark cross section can be used to identify whether a dull tool was used during butchery.

Factors influencing cut mark cross-sectional size

Skinning and disarticulation trials produced wider cut marks compared to defleshing when the entire sample of marks was considered or when average cut mark size was calculated per tool. Although skinning trials used significantly wider tools than bulk defleshing trials, the tools used for defleshing and disarticulation were similar in weight and edge angle, suggesting that the force necessary to cut through skin, tendon and ligament was greater than in oblique fillet slices, and that this difference incised further through soft tissue into the bone surface.

However, wider and deeper skinning and disarticulation marks may also be related to the less dense epiphyseal portions where these marks tend to occur. Examining the relationship of cut mark size and bone density in the defleshing mark sub-sample shows that when tool weight and edge angle are held relatively constant, EPI and NEF long bone portions have relatively wider cut marks than MSH. A non-parametric assessment suggests that wider cut marks tend to occur on less-dense bone portions in
goats and cows, but this correlation is not strong and linear. This result may come from the differences in *C. taurinus* bone density values compared with domesticates, or from the way BMD calculates density from the entire volume of bone at a particular landmark. Although this method is the most precise for calculating density, BMD may not relate directly to cortical bone hardness and texture, which are the variables assumed to affect cut mark width.

Similarly there is no positive association between post-mortem time and cut mark cross-section. In trials up to 8 hours post-mortem, rigor mortis began to stiffen joints, and superficial tissue began to dry, but this was quickly remedied by bending the joint until supple. Muscle tissue remained similar in texture and in some cases was easier to deflesh because drying muscle fascia was less slippery.

Interestingly, average cut mark width per portion is not strongly correlated across goat and cow samples, highlighting the differences in mark size across carcass size categories. Examining the plots of tool variables against average cut mark width and depth shows that, especially in the defleshing sub-sample, cow trials tend to have wider and deeper cut marks than goats at a similar edge angle or tool weight. Since cows have analogous but absolutely larger skeletons, muscles and connective tissues than goats, greater force may be employed during butchery of larger animals, producing cut marks of greater size.

Study-wide distributions of flake and core cut mark width and depth were difficult to distinguish because size distributions overlapped greatly between flake and core samples. Analyses that explored the relationship between tool variables and average cut mark size in a sub-sample of MSH defleshing marks stratified across animal size classes
suggests that cut mark width is much more strongly influenced by tool weight than edge angle, and that cut mark depth varies so little across butchery trials, that it is difficult to relate to changes in tool characteristics. Likewise, for cow trials where the forelimb, hindlimb and innominate were butchered by a single tool, average cut mark size was did not change through time as the tool dulled.

Although this study conducted many butchery episodes with a variety of tools in a realistic setting, the sample of trials used in correlation analysis was limited to between 7-10 replicates. Likewise most ANOVA test were conducted with far fewer replicates than necessary to meet the most lax sample size-power requirements. Regardless, these methods serve exploratory purposes, and are compared with non-parametric tests and visual summaries to provide a robust analysis of the relationship in question. The non-normal cut mark distributions used to generate average cut mark width per trial typically consisted of 200-400 marks, and while outlying large cut marks disrupted normality, skewness was usually accompanied by a high degree of kurtosis. Although these conditions are not ideal, they indicate that the mean is a reasonable summary measurement of cut mark size.

In general, this study suggests that butchery action (i.e. skinning and disarticulation vs. defleshing) and the bone portion where cut marks occur have greater effects on cut mark size than the edge angle or weight of a tool, or whether it is classified as a flake or core. The logarithm of tool weight was associated with significant positive change in cut mark width in the MSH defleshing sub-sample, arguing that tool characteristics do indeed affect cut mark size, but since this data is transformed, it suggests that a non-linear relationship underlies this association. Moreover, since this
relationship is not found in a wide range of experimental contexts, (i.e. in skinning or disarticulation trials), and the width of flake and core MSH defleshing cut marks are so difficult to distinguish, it is not prudent to expect the width of an archaeological cut mark to be a useful predictor of tool type.

Conclusion

Examining large samples of experimental marks produced in realistic butchery contexts shows that it is very difficult to distinguish ESA flake and core cut marks based on their cross-sectional size. Wide, deep cut marks were observed in skinning and disarticulation trials as opposed to defleshing, and were more common on larger animals in this study. The hardness and texture of bone also influences cut mark size, where the smallest defleshing cut marks occur on the most dense long bone MSH portions. Together these factors may account for differences in cut mark size that have been previously attributed to unifacial vs. bifacial or flake vs. core edge differences (Bunn, 1994, Greenfield, 2006, Shipman and Rose, 1983, Walker and Long, 1977). Although flake tools are typically light and have acute edges, and cores are heavier with more obtuse, bifacially flaked edges, both types of tools produce samples of cut marks with similar ranges of width and depth. Even when sample stratification removes the confounding influence of butchery action, carcass size and bone portion, flake and core cut marks cannot be reliably distinguished.

Other studies compare cut mark cross-sectional shape made by distinct tool edge morphological categories (i.e. metal knife edges, lithic core scrapers, flakes, and bamboo knives), but flake and core tools also vary along a continuous range of edge angle and
weight. Neither a categorical (DFA, ANOVA) or continuous approach (linear correlation and regression) for detecting differences in flake and core cut mark shape using width and depth are successful at distinguishing these groups or using edge characteristics to predict cut mark size. In sum, this suggests that a cut mark’s cross-section cannot be reliably used to infer the identity of the tool that produced it.

The findings of this study corroborate recent work on cut marks made during experimental butchery. Bello et al. (2009) used replicated handaxes to butcher a roe deer, demonstrating that archaeological cut marks on large mammalian fauna from the Acheulean site of Boxgrove were created by the pene-contemporary archaeological handaxes. The average depth of their 76 experimental cut marks is approximately 0.006 mm, which is between one and two orders of magnitude shallower than the experimental marks described here. Their experimental cut marks are also shallower than the 44 archaeological cut marks they analyze from 13 specimens, and suggest it is “plausible to infer that biologically stronger Homo heidelbergensis applied more strength to their butchering actions, resulting in the production of wider and deeper cut marks”, although “the weight of the tool or condition of the carcass” may play a role as well (1879). Variation in mark size related to individual butcher’s strength is not investigated here, and only fresh, supple carcasses were butchered, but this study demonstrates parsimonious factors, including tool weight, that influence cut mark size. The deeper cut marks produced by the modern human experimental butcher in this study may be related to bone density differences between domesticates and wild fauna at Boxgrove, indicating that the typical body size of the hominin taxon that butchered animal carcasses is not the primary cause of cut mark size. However, like this study, Bello et al. report that “[c]ut
marks close to (or on) an articulation were typically broader, deeper, and have a greater inclination”, which “may be associated with disarticulation/dismembering process [sic] that require more force” (1879). Since they analyze a single carcass that was fully butchered, it is impossible to determine if skeletal location, disarticulation versus defleshing butchery actions, or both factors were responsible for the increase in cut mark size. The data reported here suggest that these factors interact, since disarticulation produces wider, deeper cut marks, and bone density is negatively related to cut mark size.

Braun et al. (2008) corroborate the increased slicing forces necessary to skin and disarticulate carcasses compared with defleshing. They report significantly more attrition of experimental flake tool edges when skinning and disarticulating, and negligible tool damage when slicing through muscle tissue. Because cut marks are created on dense MSHs during defleshing and less-dense EPI and NEF portions during disarticulation, it is likely that edge damage is caused by repeated slicing through soft tissue as opposed to contact between the tool edge and bone surface.

Bello et al. compare archaeological cut marks on rhino, red and roe deer-size carcasses across a variety of elements and portions, and like this study, find that cut marks on “large mammal fossils were typically broader [and] deeper” than marks on fossil roe deer (1879). This set of experiments supports Bello et al.’s suggestion that “greater force… in the butchery of larger (rhinoceros-sized) carcasses” created larger cut marks, with an analysis that eliminates confounding effects introduced when comparing the size of cut marks on bone portions with different densities (1879). The number of tool strokes and time necessary to perform a butchery task is known to increase with animal
Therefore, butchery of large animals seems like a more strenuous, accident-prone behavior, which in the context of stone tool butchery, results in overestimating the force needed or the location of an anatomical target, producing wider and deeper cut marks.

**Using cut mark cross-section to help interpret ESA hominin carcass access**


On certain joints like the distal humerus/proximal radioulna where defleshing and disarticulation marks co-occur (Binford, 1978, 1981, Lyman, 2005, Nilssen, 2000), the presence of narrower marks on the humeral DNEF or olecranon process could indicate stone tool defleshing, implying hominins’ early access to meaty carcasses. In contrast, if only wide, deep marks are found around this joint, hominins might have encountered a defleshed kill that was disarticulated with stone blades. Therefore using cut mark size to infer early and late-access butchery actions can improve the behavioral resolution of the archaeological interpretations of ancient butchery traces and reconstruct a clearer picture of the carcass resources hominins exploited. Likewise, using disarticulation and
defleshing cut marks to define hypotheses of early versus late carcass access focuses analysis on certain skeletal elements and portions (e.g. the humeral-radioulnar joint), which minimizes differential skeletal portion destruction across the skeleton (see Lyman, 2005).

After individual animals or carcass parts are fragmented and disaggregated, it may be difficult to attribute carnivore tooth marking around limb joints and NEF regions to defleshing during primary carcass consumption or exploitation of scavenged within-bone nutrients. Integrating butchery action diagnosis with careful interpretations of carnivore taxon from tooth mark size and patterns of gross bone damage (see Delaney-Rivera et al., 2009 for a recent review) can strengthen inferences defining the sequence of taphonomic agents that transformed relatively complete animal parts into fragmentary skeletal assemblages.

Examining the context of butchery traces follows an interpretive approach, describing cut mark attributes on bone specimens, associated elements of an individual, or by comparing butchery evidence between sub-samples of an assemblage (i.e. mammalian size classes, age groups, or bone density categories) with reference to modern trace fossil examples. This contextual analysis adds a richer behavioral interpretation of a fossil assemblage that can supplement counts of the number of cut marked specimens in an assemblage by comparing profiles of specimens, individuals, or sub-assemblage groups that bear evidence of butchery actions representing early or late access to carcass resources (Lyman, 2005, Seetah, 2008). Of course element profiles can be misleading without consideration of the taphonomic effects of pre- and post-burial bone transport, nutritive phase and post-depositional destruction etc. (Binford, 1981,
Bonnichsen, 1989, Faith and Behrensmeyer, 2006), but this approach is more robust in light of changes to NISP than sequential models of hominin carcass access that utilize proportions of cut-marked bones in an assemblage. The difference between these approaches is analogous to the difference between qualitative and quantitative analysis, which are distinct but complementary.

To improve the resolution and strengthen the predictive accuracy of butchery trace interpretation, a larger experimental dataset would more precisely describe the variation in skeletal traces of different behavioral scenarios. Ongoing study of this experimental assemblage will investigate spatial patterning of cut mark orientation, following the predictions outlined by other researchers that suggest filleting with flake tools produces long cut marks in nearly-parallel orientation (Binford, 1981, Bunn, 1994, Nilssen, 2000, Toth, 1985).
Figure 2-1. Box and whisker plots show the distribution of experimental tool edge angle across tool type, animal size class, and butchery action factor categories. The box represents the interquartile range, where between 25% and 75% of observations occur, the whiskers extend up to the most extreme value within +/- 1.5 times the IQR, and outlying values beyond the whiskers are represented with ‘+’ symbols. The notch around the median is a visual assessment of the Kruskal-Wallis test for different medians. When notches do not overlap in a plot, medians are significantly different at p=0.05.
Figure 2-2. Box and whisker plots show the distribution of experimental tool weight across tool type, animal size class, and butchery action factor categories.
Figure 2-3. Photograph of the transverse skinning incision made with a stone tool on a cow distal metapodial.
Figure 2-4. Typical muscle scrap amount and location shown on a goat left forelimb, lateral view. Scraps of muscle represent the leftovers from removing large muscles masses, which was the beginning state in scrap defleshing trials.
Figure 2-5. Typical muscle scrap amount and location shown on a goat left forelimb, medial view.
Figure 2-6. Typical muscle scrap amount and location shown on a goat left hindlimb, lateral view.
Figure 2-7. Typical muscle scrap amount and location shown on a goat left hindlimb, medial view.
Figure 2-8. Schematic of cut mark cross-section. Width (w) is the distance to each edge of the incision into cortical bone, and includes all sub-parallel internal striae associated with an incision. Depth (d) is the perpendicular distance from the deepest point of a cut mark’s floor to the estimated cortical surface, which is modeled as a straight line between the mark’s edges.

Figure 2-9. Box and whisker plots show the distribution of cut mark width across tool type, animal size class, and butchery action factor categories.
Figure 2-10. Box and whisker plots show the distribution of cut mark depth across tool type, animal size class, and butchery action factor categories.
Figure 2-11. Box and whisker plots show the distribution of defleshing cut mark width across long bone portion categories. Cut marks on the scapula and innominate are not included.
Figure 2-12. Box and whisker plots show the distribution of defleshing cut mark depth across long bone portion categories. Cut marks on the scapula and innominate are not included.
Figure 2-13. Scatter plot matrix comparing tool variables against average cut mark size per trial. Points above the dashed line are skinning and disarticulation trials, and defleshing trials occur below the line. One disarticulation trial falls below the line in the tool weight vs. cut mark width plot, and is indicated by an arrow.
Figure 2-14. Scatter plot matrix comparing tool variables against average cut mark size in skinning and disarticulation trials. Tool weight is logarithmically transformed to bring its distribution into the normal range.
Figure 2-15. Scatter plot matrix comparing tool variables against average cut mark size on MSH portions of defleshing trials. Tool weight is logarithmically transformed to bring its distribution into the normal range.
Figure 2-16. Box and whisker plots showing the distributions of cut mark width and depth on different carcass segments for cow trials where butchery sequence was experimentally manipulated.
Figure 2-17. Box and whisker plots showing the distributions of cut mark width and depth according to the order in which forelimbs, hindlimbs and pelves were butchered in cow trials that experimentally manipulated the butchery sequence.
Figure 2-18. Box and whisker plot showing the distribution of MSH defleshing cut mark width across size class by tool type factor groups.

Figure 2-19. Box and whisker plot showing the distribution of MSH defleshing cut mark depth across size class by tool type factor groups.
Table 2-1. Experimental trials included in this study

<table>
<thead>
<tr>
<th>Trial</th>
<th>Side</th>
<th>Size</th>
<th>Action</th>
<th>Tool ID</th>
<th>Tool Type</th>
<th>Raw Material</th>
<th>Edge Angle</th>
<th>Tool Weight</th>
<th>Cut Mark Count</th>
<th>Time</th>
<th>Mean Width</th>
<th>Median Width</th>
<th>Mean Depth</th>
<th>Median Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>IB12</td>
<td>R</td>
<td>cow</td>
<td>bulk</td>
<td>C40</td>
<td>core</td>
<td>chert</td>
<td>50</td>
<td>453.0</td>
<td>565</td>
<td>39</td>
<td>0.2649</td>
<td>0.2188</td>
<td>0.0601</td>
<td>0.0625</td>
</tr>
<tr>
<td>IB15</td>
<td>R</td>
<td>cow</td>
<td>bulk</td>
<td>C41</td>
<td>core</td>
<td>chert</td>
<td>60</td>
<td>96.5</td>
<td>228</td>
<td>38</td>
<td>0.2248</td>
<td>0.1875</td>
<td>0.0561</td>
<td>0.0625</td>
</tr>
<tr>
<td>IB12</td>
<td>L</td>
<td>cow</td>
<td>bulk</td>
<td>F50-2</td>
<td>flake</td>
<td>chert</td>
<td>42</td>
<td>25.1</td>
<td>415</td>
<td>52</td>
<td>0.2561</td>
<td>0.1875</td>
<td>0.0523</td>
<td>0.0625</td>
</tr>
<tr>
<td>IB15</td>
<td>L</td>
<td>cow</td>
<td>bulk</td>
<td>F40-4</td>
<td>flake</td>
<td>chert</td>
<td>38</td>
<td>39.9</td>
<td>212</td>
<td>46</td>
<td>0.2272</td>
<td>0.1875</td>
<td>0.0597</td>
<td>0.0625</td>
</tr>
<tr>
<td>IB13</td>
<td>L</td>
<td>cow</td>
<td>scrap</td>
<td>C37</td>
<td>core</td>
<td>chert</td>
<td>45</td>
<td>731.1</td>
<td>581</td>
<td>28</td>
<td>0.2378</td>
<td>0.2188</td>
<td>0.0602</td>
<td>0.0625</td>
</tr>
<tr>
<td>IB16</td>
<td>L</td>
<td>cow</td>
<td>scrap</td>
<td>C42</td>
<td>core</td>
<td>chert</td>
<td>56</td>
<td>102.8</td>
<td>270</td>
<td>31</td>
<td>0.2324</td>
<td>0.1875</td>
<td>0.0512</td>
<td>0.0625</td>
</tr>
<tr>
<td>IB13</td>
<td>R</td>
<td>cow</td>
<td>scrap</td>
<td>F83</td>
<td>flake</td>
<td>chert</td>
<td>32</td>
<td>5.2</td>
<td>233</td>
<td>31</td>
<td>0.2122</td>
<td>0.1875</td>
<td>0.0506</td>
<td>0.0313</td>
</tr>
<tr>
<td>IB16</td>
<td>R</td>
<td>cow</td>
<td>scrap</td>
<td>F70-1</td>
<td>flake</td>
<td>chert</td>
<td>67</td>
<td>38.8</td>
<td>270</td>
<td>26</td>
<td>0.2403</td>
<td>0.1875</td>
<td>0.0543</td>
<td>0.0625</td>
</tr>
<tr>
<td>IB7</td>
<td>R</td>
<td>goat</td>
<td>bulk</td>
<td>C29</td>
<td>core</td>
<td>chert</td>
<td>43</td>
<td>24.5</td>
<td>198</td>
<td>25</td>
<td>0.1870</td>
<td>0.1563</td>
<td>0.0379</td>
<td>0.0313</td>
</tr>
<tr>
<td>Tr3</td>
<td>R</td>
<td>goat</td>
<td>bulk</td>
<td>C40</td>
<td>core</td>
<td>flake</td>
<td>23</td>
<td>20</td>
<td>0.1811</td>
<td>0.1563</td>
<td>0.0408</td>
<td>0.1563</td>
<td>0.0313</td>
<td></td>
</tr>
<tr>
<td>DB1</td>
<td>L</td>
<td>goat</td>
<td>bulk</td>
<td>C40</td>
<td>core</td>
<td>flake</td>
<td>23</td>
<td>20</td>
<td>0.1811</td>
<td>0.1563</td>
<td>0.0408</td>
<td>0.1563</td>
<td>0.0313</td>
<td></td>
</tr>
<tr>
<td>IB10</td>
<td>R</td>
<td>goat</td>
<td>scrap</td>
<td>C35</td>
<td>core</td>
<td>chalcedonay</td>
<td>45</td>
<td>50.9</td>
<td>291</td>
<td>14</td>
<td>0.1823</td>
<td>0.1563</td>
<td>0.0454</td>
<td>0.0313</td>
</tr>
<tr>
<td>IB9</td>
<td>L</td>
<td>goat</td>
<td>scrap</td>
<td>C34</td>
<td>core</td>
<td>chalcedonay</td>
<td>65</td>
<td>27.9</td>
<td>418</td>
<td>13</td>
<td>0.1734</td>
<td>0.1563</td>
<td>0.0464</td>
<td>0.0313</td>
</tr>
<tr>
<td>IB10</td>
<td>R</td>
<td>goat</td>
<td>scrap</td>
<td>F92</td>
<td>flake</td>
<td>phonolite</td>
<td>36</td>
<td>65.1</td>
<td>272</td>
<td>15</td>
<td>0.1918</td>
<td>0.1563</td>
<td>0.0507</td>
<td>0.0313</td>
</tr>
<tr>
<td>IB9</td>
<td>R</td>
<td>goat</td>
<td>scrap</td>
<td>F71</td>
<td>flake</td>
<td>ignimbrite</td>
<td>16</td>
<td>6.8</td>
<td>391</td>
<td>19</td>
<td>0.1890</td>
<td>0.1563</td>
<td>0.0458</td>
<td>0.0313</td>
</tr>
<tr>
<td>IB11</td>
<td>L</td>
<td>goat</td>
<td>skinning</td>
<td>C36</td>
<td>core</td>
<td>chalcedonay</td>
<td>70</td>
<td>53.8</td>
<td>0</td>
<td>2</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>IB14</td>
<td>R</td>
<td>goat</td>
<td>skinning</td>
<td>C30</td>
<td>core</td>
<td>ignimbrite</td>
<td>63</td>
<td>514.6</td>
<td>3</td>
<td>6</td>
<td>0.4792</td>
<td>0.4688</td>
<td>0.1458</td>
<td>0.0938</td>
</tr>
<tr>
<td>IB11</td>
<td>R</td>
<td>goat</td>
<td>skinning</td>
<td>F50-11</td>
<td>flake</td>
<td>chert</td>
<td>35</td>
<td>58.4</td>
<td>4</td>
<td>2</td>
<td>0.5000</td>
<td>0.4688</td>
<td>0.2109</td>
<td>0.2188</td>
</tr>
<tr>
<td>IB14</td>
<td>L</td>
<td>goat</td>
<td>skinning</td>
<td>F40-1</td>
<td>flake</td>
<td>chert</td>
<td>56</td>
<td>129.0</td>
<td>3</td>
<td>4</td>
<td>0.4688</td>
<td>0.4688</td>
<td>0.1979</td>
<td>0.1875</td>
</tr>
<tr>
<td>IB11</td>
<td>R</td>
<td>goat</td>
<td>disarticulation</td>
<td>C36</td>
<td>core</td>
<td>chalcedonay</td>
<td>70</td>
<td>53.8</td>
<td>82</td>
<td>11</td>
<td>0.3589</td>
<td>0.3125</td>
<td>0.0972</td>
<td>0.0781</td>
</tr>
<tr>
<td>IB14</td>
<td>R</td>
<td>goat</td>
<td>disarticulation</td>
<td>C30</td>
<td>core</td>
<td>ignimbrite</td>
<td>63</td>
<td>514.6</td>
<td>32</td>
<td>36</td>
<td>0.5083</td>
<td>0.3326</td>
<td>0.1484</td>
<td>0.0938</td>
</tr>
<tr>
<td>IB11</td>
<td>L</td>
<td>goat</td>
<td>disarticulation</td>
<td>F50-2</td>
<td>flake</td>
<td>phonolite</td>
<td>50</td>
<td>193.7</td>
<td>53</td>
<td>13</td>
<td>0.5188</td>
<td>0.4375</td>
<td>0.1297</td>
<td>0.0938</td>
</tr>
<tr>
<td>IB14</td>
<td>L</td>
<td>goat</td>
<td>disarticulation</td>
<td>F40-1</td>
<td>flake</td>
<td>chert</td>
<td>56</td>
<td>129.0</td>
<td>49</td>
<td>17</td>
<td>0.3829</td>
<td>0.3215</td>
<td>0.1122</td>
<td>0.0938</td>
</tr>
<tr>
<td>IB2</td>
<td>R</td>
<td>goat</td>
<td>skinning</td>
<td>C1</td>
<td>core</td>
<td>ignimbrite</td>
<td>75</td>
<td>704.4</td>
<td>18</td>
<td>7</td>
<td>0.2847</td>
<td>0.2188</td>
<td>0.0816</td>
<td>0.0781</td>
</tr>
<tr>
<td>IB3</td>
<td>R</td>
<td>goat</td>
<td>skinning</td>
<td>C22</td>
<td>core</td>
<td>phonolite</td>
<td>70</td>
<td>357.0</td>
<td>9</td>
<td>2</td>
<td>0.4965</td>
<td>0.3750</td>
<td>0.1389</td>
<td>0.1250</td>
</tr>
<tr>
<td>Tr1</td>
<td>R</td>
<td>goat</td>
<td>skinning</td>
<td>C34</td>
<td>flake</td>
<td>chert</td>
<td>53</td>
<td>7.6</td>
<td>2</td>
<td>2</td>
<td>0.3906</td>
<td>0.3906</td>
<td>0.1094</td>
<td>0.1094</td>
</tr>
<tr>
<td>IB3</td>
<td>R</td>
<td>goat</td>
<td>disarticulation</td>
<td>C15,C13*</td>
<td>core</td>
<td>quartzite</td>
<td>52,55</td>
<td>1033.2,215.2*</td>
<td>7,10*</td>
<td>12</td>
<td>0.3482,0.5813*</td>
<td>0.4375</td>
<td>0.0893,0.1781*</td>
<td>0.1250</td>
</tr>
<tr>
<td>IB4</td>
<td>R</td>
<td>goat</td>
<td>disarticulation</td>
<td>C7,C14*</td>
<td>core</td>
<td>ignimbrite, chert</td>
<td>52,50</td>
<td>1151.1,240.9*</td>
<td>16.40*</td>
<td>9</td>
<td>0.4775,0.3958*</td>
<td>0.3750</td>
<td>0.1367,0.1052*</td>
<td>0.0938</td>
</tr>
<tr>
<td>IB3</td>
<td>L</td>
<td>goat</td>
<td>disarticulation</td>
<td>F26,F37*</td>
<td>flake</td>
<td>chalcedonay, chert</td>
<td>17,5*</td>
<td>6,8,16,1*</td>
<td>9,43*</td>
<td>6</td>
<td>0.2465,0.2246*</td>
<td>0.2188</td>
<td>0.1007,0.0770*</td>
<td>0.0625</td>
</tr>
<tr>
<td>IB4</td>
<td>L</td>
<td>goat</td>
<td>disarticulation</td>
<td>F23,F32*</td>
<td>flake</td>
<td>ignimbrite, chert</td>
<td>38,22*</td>
<td>25,17,15,4*</td>
<td>14,24*</td>
<td>7</td>
<td>0.2969,0.3893*</td>
<td>0.2813</td>
<td>0.0915,0.1289*</td>
<td>0.0938</td>
</tr>
</tbody>
</table>

* Tool ID, edge angle, weight, and mark dimensions listed for forelimb tool and hindlimb tool respectively.
* Tool edge angle is in degrees and tool weight is in grams, butchery time is in minutes, cut mark count and mean and median cut mark size are in millimeters.
Table 2-2. Two-factor ANOVA with interaction and Kruskal-Wallis results for differences in tool edge angle across animal size class, butchery action and tool type treatment groups.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Sum Sq.</th>
<th>d.f.</th>
<th>Mean Sq.</th>
<th>F</th>
<th>p</th>
<th>Chi-sq.</th>
<th>d.f.</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>'size'</td>
<td>720.918</td>
<td>1</td>
<td>720.92</td>
<td>6.22</td>
<td>0.0220</td>
<td>1.95</td>
<td>1</td>
<td>0.1626</td>
</tr>
<tr>
<td>'action'</td>
<td>1066.3</td>
<td>3</td>
<td>355.43</td>
<td>3.07</td>
<td>0.0529</td>
<td>5.06</td>
<td>3</td>
<td>0.1672</td>
</tr>
<tr>
<td>'type'</td>
<td>2707.19</td>
<td>1</td>
<td>2707.19</td>
<td>23.35</td>
<td>0.0001</td>
<td>10.70</td>
<td>1</td>
<td>0.0011</td>
</tr>
<tr>
<td>'size*action'</td>
<td>880.852</td>
<td>3</td>
<td>293.62</td>
<td>2.53</td>
<td>0.0876</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>'size*type'</td>
<td>417.226</td>
<td>1</td>
<td>417.23</td>
<td>3.60</td>
<td>0.0731</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>'action*type'</td>
<td>89.0743</td>
<td>3</td>
<td>29.69</td>
<td>0.26</td>
<td>0.8560</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>'Error'</td>
<td>2202.47</td>
<td>19</td>
<td>115.92</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>'Total'</td>
<td>9089.22</td>
<td>31</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2-3. Two-factor ANOVA with interaction and Kruskal-Wallis results for differences in tool weight across animal size class, butchery action and tool type treatment groups.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Sum Sq.</th>
<th>d.f.</th>
<th>Mean Sq.</th>
<th>F</th>
<th>p</th>
<th>Chi-sq.</th>
<th>d.f.</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>'size'</td>
<td>58218.4719</td>
<td>1</td>
<td>58218.47</td>
<td>1.64</td>
<td>0.2163</td>
<td>2.16</td>
<td>1</td>
<td>0.1415</td>
</tr>
<tr>
<td>'action'</td>
<td>97936.6061</td>
<td>3</td>
<td>32645.54</td>
<td>0.92</td>
<td>0.4512</td>
<td>5.06</td>
<td>3</td>
<td>0.1672</td>
</tr>
<tr>
<td>'type'</td>
<td>313522.265</td>
<td>1</td>
<td>313522.27</td>
<td>8.81</td>
<td>0.0079</td>
<td>10.70</td>
<td>2</td>
<td>0.0011</td>
</tr>
<tr>
<td>'size*action'</td>
<td>105855.748</td>
<td>3</td>
<td>35285.25</td>
<td>0.99</td>
<td>0.4179</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>'size*type'</td>
<td>1200.05719</td>
<td>1</td>
<td>1200.06</td>
<td>0.03</td>
<td>0.8562</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>'action*type'</td>
<td>30991.7023</td>
<td>3</td>
<td>10330.57</td>
<td>0.29</td>
<td>0.8318</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>'Error'</td>
<td>676073.353</td>
<td>19</td>
<td>35582.81</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>'Total'</td>
<td>1313665.56</td>
<td>31</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2-4. Two-factor ANOVA with interaction on defleshing trial time across tool type and animal size class treatment groups.

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum Sq.</th>
<th>d.f.</th>
<th>Mean Sq.</th>
<th>F</th>
<th>p</th>
<th>Chi-sq.</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>'size'</td>
<td>1225.00</td>
<td>1</td>
<td>1225.00</td>
<td>21.57</td>
<td>0.0006</td>
<td>18.27</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>'type'</td>
<td>42.25</td>
<td>1</td>
<td>42.25</td>
<td>0.74</td>
<td>0.4053</td>
<td>0.39</td>
<td>0.5316</td>
</tr>
<tr>
<td>'size*type'</td>
<td>9.00</td>
<td>1</td>
<td>9.00</td>
<td>0.16</td>
<td>0.6976</td>
<td></td>
<td></td>
</tr>
<tr>
<td>'Error'</td>
<td>681.50</td>
<td>12</td>
<td>56.79</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>'Total'</td>
<td>1957.75</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2-5. Two-factor ANOVA with interaction on the logarithm of average cut mark width (top) and depth (bottom) per tool across animal size class, butchery action and tool type treatment groups.

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum Sq.</th>
<th>d.f.</th>
<th>Mean Sq.</th>
<th>F</th>
<th>p</th>
<th>Chi-sq.</th>
<th>d.f.</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>'size'</td>
<td>0.32</td>
<td>1</td>
<td>0.32</td>
<td>7.95</td>
<td>0.0114</td>
<td>0.62</td>
<td>1</td>
<td>0.4292</td>
</tr>
<tr>
<td>'action'</td>
<td>3.07</td>
<td>3</td>
<td>1.02</td>
<td>25.56</td>
<td>0.0000</td>
<td>19.89</td>
<td>3</td>
<td>0.0002</td>
</tr>
<tr>
<td>'tool'</td>
<td>0.06</td>
<td>1</td>
<td>0.06</td>
<td>1.55</td>
<td>0.2289</td>
<td>0.16</td>
<td>1</td>
<td>0.6926</td>
</tr>
<tr>
<td>'size*action'</td>
<td>0.01</td>
<td>3</td>
<td>0.00</td>
<td>0.07</td>
<td>0.9744</td>
<td>0.3516</td>
<td>1</td>
<td>0.5532</td>
</tr>
<tr>
<td>'size*tool'</td>
<td>0.04</td>
<td>1</td>
<td>0.04</td>
<td>1.03</td>
<td>0.3245</td>
<td>0.0141</td>
<td>1</td>
<td>0.9056</td>
</tr>
<tr>
<td>'action*tool'</td>
<td>0.11</td>
<td>3</td>
<td>0.04</td>
<td>0.96</td>
<td>0.4351</td>
<td>0.2450</td>
<td>1</td>
<td>0.2450</td>
</tr>
<tr>
<td>'Error'</td>
<td>0.72</td>
<td>18</td>
<td>0.04</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>'Total'</td>
<td>4.33</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum Sq.</th>
<th>d.f.</th>
<th>Mean Sq.</th>
<th>F</th>
<th>p</th>
<th>Chi-sq.</th>
<th>d.f.</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>'size'</td>
<td>0.43</td>
<td>1</td>
<td>0.43</td>
<td>10.63</td>
<td>0.0043</td>
<td>0.3516</td>
<td>1</td>
<td>0.5532</td>
</tr>
<tr>
<td>'action'</td>
<td>5.68</td>
<td>3</td>
<td>1.89</td>
<td>46.37</td>
<td>0.0000</td>
<td>22.811</td>
<td>3</td>
<td>0.0000</td>
</tr>
<tr>
<td>'tool'</td>
<td>0.00</td>
<td>1</td>
<td>0.00</td>
<td>0.03</td>
<td>0.8617</td>
<td>0.0141</td>
<td>1</td>
<td>0.9056</td>
</tr>
<tr>
<td>'size*action'</td>
<td>0.19</td>
<td>3</td>
<td>0.06</td>
<td>1.51</td>
<td>0.2450</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>'size*tool'</td>
<td>0.03</td>
<td>1</td>
<td>0.03</td>
<td>0.69</td>
<td>0.4154</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>'action*tool'</td>
<td>0.10</td>
<td>3</td>
<td>0.03</td>
<td>0.78</td>
<td>0.5194</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>'Error'</td>
<td>0.74</td>
<td>18</td>
<td>0.04</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>'Total'</td>
<td>7.32</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2-6. Bone portion density values. BMD values from *C. taurinus* (Lam et al., 1999) are compared with goat and cow mean cut mark width per portion.

<table>
<thead>
<tr>
<th>Element</th>
<th>Portion</th>
<th>Portion Code</th>
<th>BMD (_{C. taurinus})</th>
<th>mean cut mark surface width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scap</td>
<td>glenoid and tubercle</td>
<td>SP1</td>
<td>1.02</td>
<td>0.344</td>
</tr>
<tr>
<td>Scap</td>
<td>neck</td>
<td>SP2</td>
<td>1.01</td>
<td>0.234</td>
</tr>
<tr>
<td>Scap</td>
<td>ant border and basin</td>
<td>SP3</td>
<td>0.73</td>
<td>0.199</td>
</tr>
<tr>
<td>Scap</td>
<td>post border and basin</td>
<td>SP4</td>
<td>0.98</td>
<td>0.223</td>
</tr>
<tr>
<td>Scap</td>
<td>distal blade</td>
<td>SP5</td>
<td>0.50</td>
<td>n/a</td>
</tr>
<tr>
<td>Hum</td>
<td>PEPI</td>
<td>HU1</td>
<td>0.32</td>
<td>0.333</td>
</tr>
<tr>
<td>Hum</td>
<td>PNEF</td>
<td>HU2</td>
<td>0.49</td>
<td>0.216</td>
</tr>
<tr>
<td>Hum</td>
<td>MSH</td>
<td>HU3</td>
<td>1.10</td>
<td>0.248</td>
</tr>
<tr>
<td>Hum</td>
<td>DNEF</td>
<td>HU4</td>
<td>1.03</td>
<td>0.237</td>
</tr>
<tr>
<td>Hum</td>
<td>DEPI</td>
<td>HU5</td>
<td>0.51</td>
<td>0.363</td>
</tr>
<tr>
<td>Rad</td>
<td>PEPI</td>
<td>RA1</td>
<td>0.51</td>
<td>0.313</td>
</tr>
<tr>
<td>Rad</td>
<td>PNEF</td>
<td>RA2</td>
<td>1.02</td>
<td>0.228</td>
</tr>
<tr>
<td>Rad</td>
<td>MSH</td>
<td>RA3</td>
<td>1.07</td>
<td>0.221</td>
</tr>
<tr>
<td>Rad</td>
<td>DNEF</td>
<td>RA4</td>
<td>0.96</td>
<td>0.510</td>
</tr>
<tr>
<td>Rad</td>
<td>DEPI</td>
<td>RA5</td>
<td>0.47</td>
<td>1.500</td>
</tr>
<tr>
<td>Ulna</td>
<td>olecranon</td>
<td>UL1</td>
<td>0.46</td>
<td>0.278</td>
</tr>
<tr>
<td>Ulna</td>
<td>semi-lunar notch</td>
<td>UL2</td>
<td>0.85</td>
<td>n/a</td>
</tr>
<tr>
<td>Ilium</td>
<td>blade</td>
<td>IL1</td>
<td>0.39</td>
<td>0.212</td>
</tr>
<tr>
<td>Ilium</td>
<td>ramus</td>
<td>IL2</td>
<td>0.96</td>
<td>0.265</td>
</tr>
<tr>
<td>Acetabulum</td>
<td>acetabulum</td>
<td>AC1</td>
<td>0.64</td>
<td>n/a</td>
</tr>
<tr>
<td>Pubis</td>
<td>ramus</td>
<td>PU1</td>
<td>0.40</td>
<td>0.312</td>
</tr>
<tr>
<td>Pubis</td>
<td>symphysis</td>
<td>PU2</td>
<td>0.56</td>
<td>0.328</td>
</tr>
<tr>
<td>Ischiium</td>
<td>superior to acetabulum</td>
<td>IS1</td>
<td>0.92</td>
<td>0.222</td>
</tr>
<tr>
<td>Ischiium</td>
<td>tuberosity</td>
<td>IS2</td>
<td>0.31</td>
<td>0.219</td>
</tr>
<tr>
<td>Fem</td>
<td>PEPI</td>
<td>FE1</td>
<td>0.41</td>
<td>n/a</td>
</tr>
<tr>
<td>Fem</td>
<td>greater trochanter</td>
<td>FE7</td>
<td>0.31</td>
<td>0.453</td>
</tr>
<tr>
<td>Fem</td>
<td>PNEF</td>
<td>FE2</td>
<td>0.51</td>
<td>0.218</td>
</tr>
<tr>
<td>Fem</td>
<td>MSH</td>
<td>FE4</td>
<td>1.16</td>
<td>0.210</td>
</tr>
<tr>
<td>Fem</td>
<td>DNEF</td>
<td>FE5</td>
<td>0.66</td>
<td>0.207</td>
</tr>
<tr>
<td>Fem</td>
<td>DEPI</td>
<td>FE6</td>
<td>0.38</td>
<td>n/a</td>
</tr>
<tr>
<td>Tib</td>
<td>PEPI</td>
<td>TI1</td>
<td>0.42</td>
<td>0.281</td>
</tr>
<tr>
<td>Tib</td>
<td>PNEF</td>
<td>TI2</td>
<td>0.91</td>
<td>0.286</td>
</tr>
<tr>
<td>Tib</td>
<td>MSH</td>
<td>TI3</td>
<td>1.12</td>
<td>0.222</td>
</tr>
<tr>
<td>Tib</td>
<td>DNEF</td>
<td>TI4</td>
<td>1.09</td>
<td>0.242</td>
</tr>
<tr>
<td>Tib</td>
<td>DEPI</td>
<td>TI5</td>
<td>0.59</td>
<td>n/a</td>
</tr>
</tbody>
</table>
Table 2-7. Correlation between tool variables and average cut mark size. Samples are first stratified according to animal size class and then by skinning and disarticulation cut marks versus defleshing cut marks on MSH portions. Tool weight is logarithmically transformed.

<table>
<thead>
<tr>
<th>Correlation of edge angle and average cut mark width</th>
<th>Correlation of log tool weight and average mark width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson</td>
<td>Pearson</td>
</tr>
<tr>
<td>skinning and disarticulation</td>
<td>skinning and disarticulation</td>
</tr>
<tr>
<td>r</td>
<td>r</td>
</tr>
<tr>
<td>0.501</td>
<td>0.501</td>
</tr>
<tr>
<td>p</td>
<td>p</td>
</tr>
<tr>
<td>0.158</td>
<td>0.158</td>
</tr>
<tr>
<td>Spearman</td>
<td>Spearman</td>
</tr>
<tr>
<td>r</td>
<td>r</td>
</tr>
<tr>
<td>-0.491</td>
<td>-0.491</td>
</tr>
<tr>
<td>p</td>
<td>p</td>
</tr>
<tr>
<td>0.257 0.087 0.553 0.161</td>
<td>0.265 0.070 0.428 0.233</td>
</tr>
</tbody>
</table>

Table 2-8. Cow butchery trials used in tool attrition investigation. Each segment of a carcass half was butchered with a single tool without retouching to resharpen the edge. The sequence of forelimb, hindlimb and innominate butchery was evenly distributed across tool type and defleshing action experimental blocks. Cut mark cross section measured in millimeters. Time measured in minutes.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Side</th>
<th>Action</th>
<th>Tool Type</th>
<th>Tool ID</th>
<th>Segment</th>
<th>Order</th>
<th>Postmortem Time</th>
<th>Time</th>
<th>cm count</th>
<th>mean w</th>
<th>mean d</th>
<th>med w</th>
<th>med d</th>
</tr>
</thead>
<tbody>
<tr>
<td>IB12</td>
<td>R</td>
<td>bulk core</td>
<td>C40</td>
<td>fore 1</td>
<td>107</td>
<td>73</td>
<td>0.2400 0.0531</td>
<td>0.1875</td>
<td>0.0625</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IB12</td>
<td>R</td>
<td>bulk core</td>
<td>C40</td>
<td>hind 2</td>
<td>125</td>
<td>90</td>
<td>0.2137 0.0563</td>
<td>0.1875</td>
<td>0.0625</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IB12</td>
<td>R</td>
<td>bulk core</td>
<td>C40</td>
<td>pelvis 3</td>
<td>214</td>
<td>31</td>
<td>0.2617 0.0575</td>
<td>0.2500</td>
<td>0.0625</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IB12</td>
<td>L</td>
<td>bulk flake</td>
<td>F50-9</td>
<td>fore 1</td>
<td>168</td>
<td>62</td>
<td>0.1974 0.0494</td>
<td>0.1563</td>
<td>0.0313</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IB12</td>
<td>L</td>
<td>bulk flake</td>
<td>F50-9</td>
<td>hind 2</td>
<td>193</td>
<td>57</td>
<td>0.2068 0.0455</td>
<td>0.1875</td>
<td>0.0625</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IB12</td>
<td>L</td>
<td>bulk flake</td>
<td>F50-9</td>
<td>pelvis 3</td>
<td>240</td>
<td>30</td>
<td>0.2833 0.0766</td>
<td>0.2188</td>
<td>0.0625</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IB15</td>
<td>R</td>
<td>bulk core</td>
<td>C41</td>
<td>pelvis 1</td>
<td>114</td>
<td>15</td>
<td>0.2979 0.0667</td>
<td>0.1875</td>
<td>0.0625</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IB15</td>
<td>R</td>
<td>bulk core</td>
<td>C41</td>
<td>fore 2</td>
<td>226</td>
<td>36</td>
<td>0.2034 0.0590</td>
<td>0.1875</td>
<td>0.0625</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IB15</td>
<td>R</td>
<td>bulk core</td>
<td>C41</td>
<td>hind 3</td>
<td>251</td>
<td>9</td>
<td>0.3135 0.0660</td>
<td>0.3215</td>
<td>0.0625</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IB15</td>
<td>L</td>
<td>bulk flake</td>
<td>F40-4</td>
<td>pelvis 1</td>
<td>87</td>
<td>6</td>
<td>0.2031 0.0625</td>
<td>0.2031</td>
<td>0.0625</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IB15</td>
<td>L</td>
<td>bulk flake</td>
<td>F40-4</td>
<td>fore 2</td>
<td>146</td>
<td>44</td>
<td>0.2202 0.0540</td>
<td>0.1875</td>
<td>0.0625</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IB15</td>
<td>L</td>
<td>bulk flake</td>
<td>F40-4</td>
<td>hind 3</td>
<td>174</td>
<td>6</td>
<td>0.2150 0.0625</td>
<td>0.1875</td>
<td>0.0625</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IB13</td>
<td>R</td>
<td>scrap flake</td>
<td>F83</td>
<td>fore 1</td>
<td>193</td>
<td>23</td>
<td>0.2201 0.0584</td>
<td>0.1563</td>
<td>0.0625</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IB13</td>
<td>R</td>
<td>scrap flake</td>
<td>F83</td>
<td>hind 2</td>
<td>218</td>
<td>26</td>
<td>0.1851 0.0469</td>
<td>0.1563</td>
<td>0.0313</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IB13</td>
<td>R</td>
<td>scrap flake</td>
<td>F83</td>
<td>pelvis 3</td>
<td>516</td>
<td>26</td>
<td>0.2055 0.0517</td>
<td>0.1875</td>
<td>0.0625</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IB13</td>
<td>L</td>
<td>scrap core</td>
<td>C37</td>
<td>fore 1</td>
<td>141</td>
<td>58</td>
<td>0.2376 0.0555</td>
<td>0.1875</td>
<td>0.0625</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IB13</td>
<td>L</td>
<td>scrap core</td>
<td>C37</td>
<td>hind 2</td>
<td>160</td>
<td>71</td>
<td>0.2382 0.0607</td>
<td>0.2188</td>
<td>0.0625</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IB13</td>
<td>L</td>
<td>scrap core</td>
<td>C37</td>
<td>pelvis 3</td>
<td>506</td>
<td>100</td>
<td>0.2382 0.0563</td>
<td>0.2188</td>
<td>0.0625</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IB16</td>
<td>R</td>
<td>scrap flake</td>
<td>F70-1</td>
<td>pelvis 1</td>
<td>146</td>
<td>29</td>
<td>0.2643 0.0722</td>
<td>0.2188</td>
<td>0.0625</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IB16</td>
<td>R</td>
<td>scrap flake</td>
<td>F70-1</td>
<td>fore 2</td>
<td>423</td>
<td>32</td>
<td>0.2090 0.0527</td>
<td>0.1875</td>
<td>0.0625</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IB16</td>
<td>R</td>
<td>scrap flake</td>
<td>F70-1</td>
<td>hind 3</td>
<td>437</td>
<td>11</td>
<td>0.2451 0.0597</td>
<td>0.1875</td>
<td>0.0625</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IB16</td>
<td>L</td>
<td>scrap core</td>
<td>C42</td>
<td>pelvis 1</td>
<td>136</td>
<td>30</td>
<td>0.2115 0.0583</td>
<td>0.1719</td>
<td>0.0625</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IB16</td>
<td>L</td>
<td>scrap core</td>
<td>C42</td>
<td>fore 2</td>
<td>170</td>
<td>27</td>
<td>0.2044 0.0370</td>
<td>0.1563</td>
<td>0.0313</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IB16</td>
<td>L</td>
<td>scrap core</td>
<td>C42</td>
<td>hind 3</td>
<td>185</td>
<td>79</td>
<td>0.2016 0.0479</td>
<td>0.1563</td>
<td>0.0313</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

87
Table 2-9. Correlation of postmortem time and mean cut mark width and depth per segment.

<table>
<thead>
<tr>
<th></th>
<th>log width</th>
<th>log depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson r</td>
<td>0.0575</td>
<td>-0.0474</td>
</tr>
<tr>
<td>p</td>
<td>0.7895</td>
<td>0.8258</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>log width</th>
<th>log depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spearman r</td>
<td>0.0396</td>
<td>-0.0213</td>
</tr>
<tr>
<td>p</td>
<td>0.8543</td>
<td>0.9212</td>
</tr>
</tbody>
</table>

Table 2-10. Classification of MSH defleshing cut marks with discriminant analysis using log width and log depth.

<table>
<thead>
<tr>
<th></th>
<th>number of cut marks</th>
<th>% cut marks misclassified</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>core</td>
<td>width</td>
</tr>
<tr>
<td>cow</td>
<td>261</td>
<td>443</td>
</tr>
<tr>
<td></td>
<td>flake</td>
<td></td>
</tr>
<tr>
<td>goat</td>
<td>274</td>
<td>359</td>
</tr>
<tr>
<td></td>
<td>core</td>
<td></td>
</tr>
<tr>
<td></td>
<td>flake</td>
<td></td>
</tr>
</tbody>
</table>
Chapter 3: The utility of cut mark cluster geometry for distinguishing flake versus core tool butchery and the amount of flesh removed

Abstract

A lack of inferential clarity plagues interpretations of Oldowan hominins’ tool use during butchery and their paleoecological position in the carnivore guild because the cut mark signatures of flake versus core tool use and the diagnostic traces of bulk muscle removal versus muscle scrap defleshing have not been carefully documented. Half-carcass trials were conducted by an experienced butcher on domestic cows and goats using a single replicated Oldowan flake or bifacial core in each trial to quantify the effect of tool type and the amount of flesh removed on cut mark cluster geometry. Clusters of defleshing cut marks are defined as series of striae with parallel, sub-parallel, or intersecting orientation, and are spatially distinct from other clusters of marks on a skeletal portion. Clusters of cut marks were molded with dental putty and photographed, and cluster attributes including median cut mark length, standard deviation of cut mark length and angle, and the area within the perimeter of cut mark end points was measured.

The experimental sample was stratified across animal size class and into groups that included all multiple-mark clusters, and all clusters on long bone shafts. Log-transformed cluster attributes were also averaged for each trial. Differences in cluster geometry were rarely detected between tool types or defleshing actions, and these
differences never existed in both goat and cow samples. Linear discriminant analysis using variable pairs to test identification of known cluster origin within size class failed to correctly assign clusters in 40-74% of cases.

Log tool weight was significantly positively correlated with cluster attributes in cow trials, but not in goat trials. In contrast, no relationship was detected between tool edge angle and cluster attributes in either animal size class.

Log cut mark length standard deviation was significantly and strongly positively correlated with log cluster area in all sample stratifications. Log cut mark angle standard deviation was significantly, but moderately positively correlated with log cut mark count in all sample stratifications except when goat clusters were averaged per trial.

Cluster attributes were not significantly impacted by experimental manipulation of the order in which cow limb segments were butchered, and postmortem time (up to 8 hours) is not significantly correlated with median cluster attributes per segment, suggesting that neither tool dulling during the butchery process or the onset of rigor mortis affect cluster geometry.

In sum, cut mark cluster attributes like mark length and angle dispersion, which were assigned behavioral associations with flake or core tool types in archaeological interpretations vary little across these experimental factor categories, and can alternatively be explained by increasing cut mark count and cluster area. Actualistic experiments that realistically model contingencies encountered during stone tool butchery, including animal size and musculo-skeletal differences across bone portions are necessary to illuminate these relationships.
Introduction

Early Pleistocene cut marked bone evidence documents one of the earliest uses of human technology to enhance foraging opportunities, an ecological shift that expanded hominins’ niche to include higher quality carcass resources (Bunn, 1981, Potts and Shipman, 1981). Cut marked bone therefore has the potential to shed light on two important components of the paleoecology of human carnivory: the nature of hominins’ carcass acquisition and competition with other carnivores, and Oldowan tool function and use during the butchery process.

However, the data necessary to connect cut mark traces to the behaviors that created them have only been partially collected and rarely synthesized, preventing a general interpretation of ancient butchery evidence (Lupo and O’Connell, 2002). This stems from different strategies for counting cut marks and butchered specimens and the behavioral interpretations they allow, especially when individual animals or limb elements are reduced to unidentifiable bone fragments. This chapter explores the utility of cut mark cluster geometry as an interpretive framework for inferring both the amount of meat butchered from a carcass and whether flake or core tools were used during butchery. Before these higher range inferences can be substantiated and used in archaeological interpretation, actualistic experimentation should determine whether these butchery factors create distinct, identifiable signatures on the skeleton (Gifford-Gonzalez, 1991).
Butchery interpretation using cut mark data: a brief history and the current perspective

Recent works (Dominguez-Rodrigo, 2008, Nilssen, 2000, Pobiner, 2008) review the history of actualistic taphonomy in detail, much of which focused on identifying the signatures of different taphonomic agents on fragmentary bone assemblages to determine whether Early Pleistocene hominins were agents of bone accumulation during site formation processes (Shipman and Rose, 1984, Bunn, 1981, Potts and Shipman, 1981, Blumenschine and Selvaggio, 1988). After establishing that both hominins and carnivores actors (in addition to other abiotic factors) had the potential to accumulate, modify and subtract bone (through physical destruction or reducing their identifiability), the order and magnitude of their bone modification was explored, much of which focused on interpreting whether the FLK 22 (Zinjanthropus) assemblage represented the butchery traces of hominins successfully acquiring large mammalian prey or scavenging the remains of carnivore kills.

This approach includes the bone assemblage-scale analyses where frequency of cut marked specimens are interpreted in light of actualistically-derived sequential models of carcass consumers’ bone modification (Blumenschine, 1986, 1988, 1995, Capaldo, 1997, 1998, Dominguez-Rodrigo, 1999, Lupo and O’Connell, 2002, O’Connell et al., 1992, Selvagio, 1994, 1998). Here the proportions of butchered and carnivore tooth marked specimens reflect primary or secondary hominin access to carcasses during assemblage formation, but fragmentation and specimen dissociation during bone consumption or during an assemblage’s taphonomic history may impact this interpretation. These studies count butchered specimens and attribute butchery behavior
to cut marks based on their skeletal location on a bone portion scale, and have prompted a
debate surrounding the idea that cut marks on long bone midshafts exclusively represent
butchery of fully-fleshed limbs (Bunn, 2001, Dominguez-Rodrigo, 1999). However, they
do simulate realistic scenarios of carcass consumption, and interpret hominins’ ecological
position by inferring the activity of ancient hominins and carnivores in the sequence of
taphonomic agents that created a butchered bone assemblage.

Other actualistic studies investigate cut marks themselves, aiming to interpret the
tissues butchered from a carcass using cut mark location, count, and orientation on a
specimen, and interpret assemblage-scale butchery behavior from lists of butchered
specimens (Bunn, 1994, Dominguez-Rodrigo et al., 2005, Nilssen, 2000). These studies
allow a more detailed interpretation of butchery behavior from cut mark data but may not
always be based on a secure actualistic framework, and are rarely described with
complementary detail about carnivore tooth marking. Cut mark location and orientation
are useful for gross distinctions between defleshing and element disarticulation, but
certain skeletal portions like the posterior aspect of the distal humerus may preserve
similar cut mark traces when muscle is filleted or the humeral-radioulnar joint is
disarticulated (Binford, 1978, Nilssen, 2000). Likewise, when defleshing cut marks occur
on long bone shaft portions, it is difficult to relate the abundance of cut marks to the
amount of flesh removed (Egeland, 2003, Pobiner and Braun, 2005) and the previous
chapter of this dissertation further contradicts the idea that cut marks on midshaft
portions only reflect large muscle mass removal. Fragmentation and dissociation of
specimens which were once part of the same element or individual impacts
interpretations of individual cut marks since even with high-resolution behavioral
interpretations of cut mark traces, if the entire individual (or limb segment which was butchered) is represented by a single fragmentary specimen, it is difficult to reconstruct with confidence the sequence and activity of carcass consumers.

Careful actualistic research into the effectiveness of distinct stone tool classes for different butchery tasks has been conducted (Frison, 1989, Jones, 1980, Toth, 1985) but cut mark traces have rarely been used to support inferences about Oldowan tool function, aside from the simple demonstration that any sharp-edge tool incises cut mark striae in the cortical surface during the butchery process. However, Bunn (1994) describes a basin-scale foraging strategy that included raw material conservation and carefully controlled flaking to produce large cutting tools which were used to butcher large carcasses, particularly hippos during the Okote member at Koobi Fora. Raw material selectivity and tool curation are documented foraging strategies during Oldowan times (Braun et al., 2008a, 2009a, 2009b), but Bunn’s archaeological argument is not supported by an experimentally-based interpretive framework that distinguishes flake and large cutting tool butchery.

Here we are reminded of the equifinalities that obscure behavioral inferences from archaeological data. Cut marks represent butchery with sharp edged tools, but both flakes and cores are equally likely candidates. Early actualistic butchery experiments produced mixed results, with some suggesting that core tools are more efficient for butchery of large animals (Jones, 1980), whereas others concluded that flakes were the intended multi-purpose cutting tools, and different core forms represent distinct moments in the reduction sequence (Toth, 1985). Although none of these studies examined differences in the skeletal traces of butchery with flakes and cores, Toth depicts
hypothesized cut marks made by flakes, unifacial flake scrapers and bifacial handaxes (1985:112). Flakes are suggested to make single striations, and the number of striae increase and the angles and lengths of marks are more scattered with scrapers and handaxes. These hypotheses imply that as a tool’s edge gets more robust, and tool size increases, clusters of marks become larger with striae that are more scattered and in less-parallel orientation.

Recently de Juana et al. (2010) published an actualistic experiment that suggests flake and handaxe marks can be distinguished because handaxe marks have greater numbers of striae and more intersecting striae in a cluster of cut marks. In their study, most cut marks were intentionally incised at either an oblique or perpendicular angle with a single slice across the surface of a completely defleshed deer limb bone, and only two limbs were actually defleshed with stone handaxes. Regardless, their small sample of experimental cut marks is cast as representative of the global population of handaxe cut marks despite failure to realistically model the butchery process. The contingencies encountered during butchery including animal size class, or anatomical differences in muscular terminations or attachment sites, surely affect whether multiple, overlapping cutting strokes were necessary, or the tool had to be held at different angles. This study points out the need for actualistic studies that model realistic butchery scenarios and explore cut mark production as an incidental by-product of butchery, and highlights the lingering confusion over counting cut marks.

A cut mark is currently defined in two ways by different researchers. The earliest Plio-Pleistocene cut mark descriptions implied that each striation in the bone surface should be considered a cut mark, but that these striae commonly occur in parallel
orientation and close proximity (Bunn, 1981, Potts & Shipman, 1981). Many recent studies into cut mark production count each striation as a single cut mark (e.g. Braun et al., 2008b, Egeland, 2003, Pobiner and Braun, 2005, West and Luoys, 2007). Other researchers suggest that each set of multiple striae that seem functionally related to the same slicing motion should be tallied as a single cut mark (Dewbury and Russell, 2007, Lyman, 2005, de Juana et al., 2010). Regardless of whether a set of ten cut mark striae is counted as one or ten marks, the geometric properties of these cut mark clusters has never been carefully studied to examine whether clusters of cut marks can be used to interpret the type of tool that created them or the amount of flesh removed.

Methods

Experimental design

This study examined cut marks produced during experimental butchery trials with the ultimate goal of documenting cut marks traces that can be used to infer the amount of flesh removed during butchery and identifying diagnostic cut mark traces that could be used to distinguish butchery conducted with flake tools versus bifacial cores. Butchery trials consist of half-carcass replications of fore- and hindlimb musculo-skeletal units without phalanges on domestic goats (Capra hircus) and cows (Bos taurus). The sample of 16 butchery trials follows a full factorial design with two half-carcass replications of each tool type/action/size treatment (Table 3-1).

Experimental Butchery Procedure
A Dassenech man experienced in livestock butchery conducted all trials to eliminate individual variability in cut mark production. The butcher was offered a choice of replicated Oldowan unmodified cortical and non-cortical flakes and bifacially flaked cores made from raw materials that also occur in Early Pleistocene archaeological deposits at Koobi Fora. He was asked to select a flake or core which best suited the task, and to perform each butchery action as efficiently as possible. The butcher was naïve of the cut mark analysis and cut marks were not intentionally produced. Tools were never retouched during butchery and a single tool was used to deflesh both the fore- and hindlimb of a half-carcass trial. Butchery trials were recorded on video and timed to the nearest minute.

Tool edge angle was measured with a goniometer at the most obtuse point along the cutting edge and tool weight was measured to the nearest gram with a digital scale. In three pilot butchery trials included in this study, tools were not retained and edge angle was not recorded. Comparing experimental tool characteristic distributions across treatment groups is the visual equivalent to the non-parametric Kruskal-Wallis test for equivalent group medians. The core sample of tools had a significantly wider median edge angle than the flake sample (Figure 3-1). The median tool edge angle in animal size and defleshing action groups are indistinguishable, indicating that these treatment groups were butchered with samples of tools with similar edge angles. Median tool weight is equivalent across animal size class, defleshing action, and tool type groups, although cows tended to be butchered with heavier tools. The core sample is almost significantly heavier than the flake sample (Figure 3-2). Regardless, analyses of cut mark cluster geometry are typically stratified across animal size class categories, to examine how the
relationship of cluster attributes and butchery factors is affected by the size of the animal being butchered.

Carcass segment skinning was conducted with a transverse incision around the distal metapodials, which was continued superiorly along the medial aspect of each limb. A metal knife and the butcher’s hands were used to skin the remainder of the carcass. Skinning cut marks occurred primarily on the metapodials and occasionally on the carpals and tarsals, and were excluded from this analysis. Before defleshing, each limb was disarticulated from its girdle with a metal knife, which produced no cut marks on the forelimb, but to a varying extent incised the femoral head, inferior neck, and acetabulum. This process was video-recorded and metal knife cut marks were located by consulting the butchery record, identified according to their acute, deep cross section (Blumenschine et al., 1996), and excluded from analysis. In goat trials, the pelvis was defleshed while articulated to the axial skeleton, but in cows, it was removed before defleshing by chopping through the articulation between the first few lumbar vertebrae with a machete.

Bulk muscle defleshing targeted the large muscle groups of the fore- and hindlimbs including the scapula, innominate and lumbar vertebrae. The metapodials and phalanges were not defleshed since they are encased only in tendon. The butcher was asked to remove as much flesh as necessary, without disarticulating the bones, to expose the majority of the bone shaft so that fragmentation with a hammerstone and anvil would be possible. The periosteum was not removed. Typically, this resulted in remnants of adhering flesh around joints and at some muscle attachment sites (see Figures 2-4 – 2-7).

Muscle scrap defleshing targeted deep muscles surrounding joints and the small scraps of flesh remaining near their skeletal or tendonous attachment sites on fore- and
hindlimbs, excluding the metapodials or phalanges. Scrap defleshing targeted flesh that remained after bulk defleshing, but these trials were conducted separately (see Figures 2-4 – 2-7). Bulk muscles were removed carefully with a metal knife and this process was observed closely and video-recorded. Metal knife preparation marks were identified based on the location indicated in the butchery record, identified by their cross-section, and excluded from analysis. Goat and cow limbs typically yielded between 250 to 500, and 500 to 1000 grams of muscle scraps respectively, which were concentrated on the scapula, innominate, and around joint capsules.

**Bone Specimen Preparation**

Bones were boiled for 4-8 hours in saline-alkaline lake water, and adhering soft tissue was removed by hand. A second boil in an approximately 1:1000 solution of hydrogen peroxide and water for 4-8 hours was conducted after two holes approximately two millimeters in size were drilled into long bones’ medulary cavities to aid degreasing. Trials requiring additional degreasing were boiled for a third or fourth session under the same conditions. Bones were air-dried after boiling and were considered degreased when fatty residues no longer covered the dry bone surface.

**Cut mark cluster identification, molding, & photography**

Each cluster of cut marks was identified with the naked eye and hand lens magnification (between 10-16X) as a series of cut mark striae that are parallel or sub-parallel in orientation, or may intersect. Most clusters contain multiple marks and were
distinctly separated from other clusters by areas of bone without cut marks. However some clusters occur as single cut marks (hereafter called singleton clusters), which did not occur in close parallel orientation to, or intersect with another mark. Singletons were attributed to a cluster when they were in near-parallel orientation, or occurred within the distance of the longest mark to the center of the clearly defined cluster. Defleshing cut mark clusters seem to be related to filleting a particular anatomical area or severing tendonous attachments, and certainly come from multiple slices. These also may come to be overprinted cuts on the same area from different filleting episodes.

Working with one element at a time, clusters of cut marks were circled with pencil on bone specimens and molded with 3M Express vinyl polysiloxane bite registration putty. After a mold solidified, every cut mark was traced carefully with a fine mechanical pencil (0.5 mm point size) that provided excellent contrast for photography. A millimeter scale and both transverse and superior-inferior axis labels were framed inside a digital photograph at 8 megapixel resolution of varying zoom (Gilbert and Richards, 2000). To minimize parallax in cut mark geometry, cluster mold photographs were taken at close range, directly above the cluster, while visually checking the scale to ensure that the mold and scale were oriented on the same horizontal plane. Photographing cluster molds with this technique was discovered in a pilot study to be much easier than attempting to capture every cut mark in a cluster on an often curving bone surface, which required precise focus and depth of field adjustments, as well as intense light at a low angle of incidence to the cortical surface.

Cluster variables measured
Cluster photographs were saved as high-resolution JPEG images and analyzed in ImageJ 1.41o (http://rsb.info.nih.gov/ij), a free open-source image analysis program (See also O’Connell or Dom-rod recent paper since they use it) (Figure 3-3). The same 10 mm section of scale was used to calibrate distance on all photographs. The angle of the transverse bone axis was recorded from the photograph so that adjustments could be made if the specimen was not framed parallel to this axis. Straight lines were drawn over traced cut marks and each mark was numbered and measured for length and angle. When cut marks were not completely straight, lines that best represented the general angular trend of the mark and measured its distance accurately were drawn. A polygon was drawn between adjacent end points of the cut marks that defined the perimeter of the cluster and minimized its internal area.

ImageJ measures angle on a scale of 0-360 degrees, which can accurately reflect the direction in which a cut mark was incised. However, identifying the cut mark direction was not as important in this study as measuring the variation in cut mark orientation within a cluster, therefore all measurements were converted to a scale of 0-180 degrees. This conversion eliminates the faulty mathematical effects that would occur when complementary angles in a cluster were summarized. (For example a cluster containing a mark angled at 90 degrees and 270 degrees would represent two marks that have the same orientation on the transverse axis. Without this conversion their standard deviation would erroneously be reported as 127.3 degrees as opposed to zero.)

These measurements were used to generate the following cluster variables: cut mark count, cluster area, median cut mark length, standard deviation of length, and
standard deviation of cut mark angle. The median was selected to summarize cut mark length per cluster since it is more appropriate for clusters with marks whose extreme lengths would exaggerate the group summary value. Standard deviation was selected to describe variation in cut mark length and angle per cluster as opposed to range, because although it relies on differences from a mean value, it is sensitive to the number of marks per cluster.

Hypotheses tested

Two main hypotheses were explored in cow and goat size class samples to determine whether cut mark clusters can be quantitatively distinguished across experimental butchery treatment factors.

Muscle scrap defleshing targets the insertions and origins where muscle or tendon attaches to bone. These small scraps are often slippery and cannot as easily be held taught to allow efficient slicing compared to the large muscle masses targeted in bulk defleshing. Scrap defleshing is predicted to require more butchery strokes and greater slicing effort at any musculoskeletal landmark compared to defleshing bulk muscles, and is predicted to make clusters that are more densely packed with shorter cut marks that have more uniform angle. Specifically, compared to bulk muscles masses, defleshing muscle scraps is predicted to create clusters with a greater number of cut marks, greater area, shorter median marks, and greater standard deviation of cut mark length and angle. Scrap defleshing is predicted to make more clusters on all long bone shaft portions, but particularly on near-epiphyseal portions. Regardless of defleshing action, butchery time is
expected to correlate positively with cut mark count, cluster area, and standard deviation of cut mark length and area when all clusters are summarized per trial.

Cores have more obtuse edge angles and are typically heavier, making them more unwieldy when completing the same butchery task compared to flakes. Therefore they are predicted to make clusters of cut marks with less uniform spatial organization that are more densely packed with shorter cut marks. Specifically, compared to flakes, core clusters are predicted to have greater numbers of marks, greater area, shorter median marks, and greater standard deviation of cut mark length and angle. Additionally, tool weight and edge angle regardless of flake or core tool type are expected to correlate positively with cut mark count, cluster area, standard deviation of length and angle, and negatively with median cut mark length when all clusters are summarized per tool. During the butchery process, tools are expected to dull and become harder to use, therefore it is expected that cluster area, cut mark count, and standard deviation of length and angle per cluster will increase throughout the tool’s use life.

To build a general model where cluster attributes can be used to infer butchery action or tool type for any animal size, skeletal element, or portion, it is hypothesized that treatment factors’ effects on cut mark count, area or organization of cut mark clusters, will be apparent for goats and cows on all scales of analysis: all multiple mark clusters, long bone shaft clusters, and cluster summary measurements per tool.

Results

Butchery trial time
Butchery trials took significantly longer in cows compared to goats in all experimental trials. In contrast, the sample of bulk and scrap defleshing trials had equivalent median butchery times across both animal size classes and tool type categories. Likewise, the sample of defleshing trials conducted with core tools had an equivalent medial time to the sample of flake defleshing trials in the total sample (Figure 3-4).

Correlation of butchery trial characteristics and cluster attributes

Each butchery trial was completed with a single tool. The mean of log transformed cluster attributes was calculated per tool in the goat and cow samples. No single variable is significantly correlated with tool edge angle for either size class (Table 3-2). Log tool weight has a strong positive correlation with mean log cut mark count, cluster area and standard deviation of cut mark angle in the cow sample, however none of these relationships are observed in the goat sample.

Butchery time per trial has no significant relationship with any cluster attribute for cows or goats.

Cluster count and location

Table 3-3 shows the total count of multiple mark clusters and singletons in all butchery trials stratified by animal size class, butchery action and tool type. More clusters
occur on cows compared to goats, but neither butchery action or tool type has a clear influence on cluster count. A chi squared test shows that within a size class, tool type and butchery action do not strongly influence the count of singleton clusters (Chi-squared = 4.82, p = 0.19, d.f. = 3 for tool type, and Chi-squared = 3.90, p = 0.27, d.f. = 3 for action). For multiple mark clusters, tool type does not influence cluster count in the entire sample (Chi-squared = 1.80 p = 0.62, d.f. = 3), but butchery action is associated with differences in cluster count (Chi-squared = 28.51, p < 0.0001, d.f. = 3). However, this association may be fortuitous since in the cow sample, bulk defleshing produced more clusters than expected, whereas in goats, scrap defleshing produced more clusters than expected.

On long bone shaft portions, the count of multiple mark clusters in all trials has no clear relationship with either bulk or scrap muscle defleshing or flake versus core tool type (Table 3-4). Wilcoxon sign rank tests indicate that the count of clusters per portion cannot be distinguished across defleshing actions or tool types (p = 0.39 and 0.37 respectively). The anatomical distribution of cut mark cluster per portion indicates that while bulk defleshing created more clusters on MSH portions compared to NEFs, scrap defleshing also created marks on long bone MSHs.

**Cluster size:**

*Cut mark count per cluster*

Notched boxplots indicate that median cut mark count per cluster is significantly greater in bulk defleshing than scrap defleshing in the cow size class, but indistinguishable in goats (Figure 3-5). These boxplots are a visual representation of the
Kruskal-Wallis test at a $p$ value of 0.05 and indicate that cut mark count distributions are right-skewed, warranting caution in their use in analyses that assume a normal distribution for data. When singleton clusters are removed, bulk and scrap defleshing median cut mark counts in multiple mark clusters are identical in both cow and goat categories (Figure 3-6). Similarly, median cut mark count cannot be distinguished for flake and core groups within animal size class categories when all clusters are considered or in clusters with multiple cut marks. In general, cows and goat make clusters with similar numbers of marks regardless of tool type (Figures 3-7 and 3-8).

The lack of significant differences between bulk and scrap defleshing cut mark counts also occurs when long bone shaft portions are examined. In cows, boxplots comparing bulk and scrap defleshing cut mark count on long bone shaft portions from all trials show significantly higher median cut mark counts for bulk defleshing in the humeral distal near-epiphyses (DNEF), radial proximal near-epiphyses (PNEF), and tibial DNEF, although the scrap samples in the later two comparisons include only one cluster (Figure 3-9). The goat sample shows only one significant difference, where defleshing scraps form the humeral PNEF creates more marks per cluster than bulk defleshing, although this comparison is limited by a single observed bulk defleshing cluster (Figure 3-10). In cows, cores created significantly more cut marks on only the femoral PNEF, DNEF and the tibial midshaft (MSH) (Figure 3-11). In goats, flakes made significantly more marks per cluster on the radial DNEF than cores, but each tool type only introduced a single cluster onto this portion in all four trials (Figure 3-12).

Cluster area
Cluster area distribution in size class by action and tool type groups is right skewed with outliers of very large area (Figures 3-13 and 3-14). Median cluster area does not differ between bulk and scrap defleshing actions in goat or cow size classes. Cows have clusters of larger area in general, but the smaller median scrap defleshing cluster area in cows overlaps with the larger goat, bulk defleshing sample median. Similarly, flake and core cluster samples have indistinguishable median areas in the goat and cow samples, and the clusters made by cores in the cow sample have a significantly larger median area than goat clusters made by either type of tool.

In cow long bone portions, bulk defleshing creates clusters of larger median area than scrap defleshing on the humeral and femoral DNEF, as well as the radial PNEF and tibial DNEF, although the later two comparisons are influenced by single clusters in the scrap defleshing sample (Figures 3-15 and 3-16). In goats, the humeral PNEF contains scrap defleshing clusters that are significantly larger than bulk defleshing, a reversal from the cow pattern that is influenced by the single observed bulk cluster. No significant differences in cluster area were observed across tool type comparisons for cow or goat long bone portions (Figures 3-17 and 3-18).

*Median cut mark length per cluster*

In singleton clusters, cut mark length distributions are indistinguishable between both bulk and scrap defleshing and flake and core treatments within animal size class comparisons (Figures 3-19 and 3-20). The medians of multiple mark cluster median cut
mark length cannot be distinguished between action or tool type categories in either animal size class, however all cow cluster samples have significantly longer median cut marks than goat samples (Figures 3-21 and 3-22).

When long bone shaft portions are compared between defleshing action in cow trials, median cut mark length per cluster is significantly longer in bulk defleshing trials for the humeral PNEF. The radial PNEF scrap defleshing sample has a significantly longer median mark, but this difference is compromised by the single observed cluster (Figures 3-23). In goats, femoral MSH and PNEF clusters in bulk defleshing trials had significantly longer median cut marks than scrap defleshing clusters, although only one cluster on the PNEF was introduced during bulk defleshing (Figure 3-24). Significant differences do not exist across tool type comparisons except for the significantly shorter clusters created by flakes on the cow tibial DNEF and goat radial DNEF, and significantly longer clusters created by flakes on the goat radial PNEF, although all of these differences are influenced by the single clusters comparisons (Figures 3-25 and 3-26).

**Cut mark organization:**

*Standard deviation of cut mark length*

The median standard deviation of cut mark length is not significantly different in animal size class categories for butchery action or tool type comparisons (Figures 3-27 and 3-28). However, in action and tool type comparisons, cow clusters have significantly more standard deviation of length than goat clusters.
In cow long bone portions bulk defleshing clusters have more uniform length than scrap defleshing clusters on the humeral PNEF and tibial DNEF, but the later comparison is influenced by a single cluster in the scrap sample (Figure 3-29). The goat sample comparisons indicate that bulk defleshing clusters have more uniform length, in the humeral PNEF, radial PNEF and femoral PNEF, but all of these comparisons are influenced by boxplots that contain a single cluster (Figure 3-30). Comparing tool type across cow long bone portion yields no significant differences except for a single tibial DNEF core cluster that has more uniform length than the flake sample (Figure 3-31). Similarly, in goats, the only differences are artifacts of single clusters on the radial PNEF where the flake cluster has a higher standard deviation of length than the core clusters, and the radial DNEF where both flake and core categories have a single cluster, but the marks created by the core are more dispersed with respect to length (Figure 3-32).

*Standard deviation of cut mark angle*

It is not possible to distinguish the median standard deviation of cut mark angle for multiple mark clusters across the bulk and scrap defleshing comparison within animal size classes. In addition, goat and cow samples possess equivalent median values for standard deviation of cut mark angle (Figures 3-33). For tool type comparisons, angle standard deviation is equivalent in animal size classes, and the goat core sample has a significantly higher median value than the cow flake sample (Figure 3-34).

For defleshing clusters on cow long bone portions, the only difference occurs in the humeral DNEF sample, where bulk defleshing clusters have a higher median angle
standard deviation than scrap defleshing clusters (Figure 3-35). Among goat long bone portions, bulk defleshing clusters have significantly higher median angle standard deviations in the humeral MSH and tibial MSH, but scrap defleshing produced clusters with more standard deviation of cut mark angle in the femoral DNEF and humeral PNEF, although a single bulk defleshing cluster influences this last comparison (Figure 3-36). When tool types are compared on cow long bone portions, the femoral DNEF clusters made by cores had a significantly higher median angle standard deviation (Figure 3-37). In the goat sample, cores made clusters with significantly higher median angle standard deviation on the olecranon process of the ulna and the femoral PNEF (Figure 3-38).

Correlation of cluster variables

Correlations between cut mark count, cluster area, median length, standard deviation of length and standard deviation of angle are calculated for log transformed values of multiple mark clusters, log transformed values of long bone shaft clusters and the mean of log transformed multiple mark cluster values per tool for cow and goat samples (Table 3-5).

Cut mark count has a strong positive correlation with cluster area for goats and cows when clusters are examined on the whole skeleton, long bone shafts or summarized as means of log values per tool. Standard deviation of cut mark length has the strongest positive correlation with cluster area for cows and goats in all cluster scales. Standard deviation of length has a strong positive correlation with median cut mark length and a moderate positive correlation with cut mark count except in the tool-scale summary for
cows. Standard deviation of cut mark angle is more strongly correlated with cut mark count than cluster area for all clusters and the long bone shaft sample, and has no relationship with length standard deviation. When summarized per tool, the relative strength of these correlations in unchanged in the cow sample, but in goat trials, no relationship between standard deviation of cut mark angle and any other variable exists.

Principal components analysis on standardized log transformed values of multiple mark clusters yields very similar results for goat and cow samples and supports the correlation between cluster attributes (Table 3-6). All variables except angle standard deviation contribute strongly toward the variance explained by the first principal component. The second axis displays variation in sample values introduced by angle standard deviation, along with residual variation from median length and cut mark count. Together, the first two linear combinations of variables explain over 80% of sample variance. The third principal component expresses further residual variation introduced mainly by angle standard deviation and cut mark count. The first three principal components explain over 92% of sample variance.

*Discriminant analysis of cluster attributes in butchery action and tool type groups*

Separate linear discriminant analyses were carried out on log transformed cluster variable pairs in cow and goat samples from the entire skeleton or only long bone shafts (Table 3-7). This technique examined cluster variables predicted to vary with the type of tool used during butchery or the amount of flesh removed. The analysis first attempted to distinguish clusters made during bulk versus scrap defleshing butchery actions, and a
second analysis aimed to discriminate clusters produced by flake versus core tools. A final analysis attempted to classify clusters to the butchery action and tool type that created them. The distributions of cluster attributes overlap greatly between experimental factors, which leads to poor classification with discriminant analysis.

In the multiple mark clusters and the long bone shaft sample, the similarity of log cut mark count and log area, log standard deviation of length and log area, log standard deviation of angle and log area, and log median cut mark length and log area leads to a 40-50% misclassification rate in both cows and goats when discriminating either butchery action or tool type. When attempting to assign clusters to the appropriate butchery action and tool type, the error rate increases to nearly 65-75% in cows and goats.

Discriminant analysis returns similar classification error rates when scores from the first three principal components are used to clusters in goat and cow samples (Table 3-7). Figures 3-39 and 3-40 plot the first two principal component axes for cows and goats, and show the overlap of clusters made by different defleshing actions and tool types when all cluster attributes are considered together.

_Butchery sequence analysis_

In the cow sample, a single tool was used in each defleshing trial, and never retouched, allowing an examination of how the order of forelimb, hindlimb and innominate butchery affects cut mark cluster geometry (Table 3-8). Forelimbs were always butchered before hindlimbs, but in half of the cow trials, the innominate was
defleshed first. Defleshing action, tool type and the sequence of carcass segment butchery of each trial followed a full-factorial design.

As defleshing trials progressed, tools edges were presumed to dull. This is difficult to measure, but fatty, soft-tissue residue was observed to cover the cutting edge, which compromised the cutting effectiveness of the tool until this sticky substance was manually removed. This reduction in cutting efficiency is predicted to require more cutting strokes and therefore predicted to increase the number of cut marks per cluster, cluster area, and the standard deviation of cut mark length and angle. To ensure cluster attributes are not confounded by differences in musculo-skeletal anatomy and the size of epiphyseal bone portions, this analysis examines only long bone shafts and the dense, shaft-like portions of the innominate, which exclude the acetabulum, iliac blade, and ischial tuberosity.

When clusters from forelimb, hindlimb or innominate segments in all trials are examined, no significant differences in cut mark count, cluster area or standard deviation of cut mark length or angle are identified (Figure 3-41). When different butchery sequences are examined on forelimbs, hindlimbs and innominates, samples of cluster attributes cannot be distinguished based on the order in which defleshing occurred (Figure 3-42).

The time since slaughter might also affect cut mark cluster geometry because desiccation and rigor mortis may affect the ease of defleshing muscles (Lupo, 1994). While all butchery trials took place less than nine hours postmortem, both sides of the innominate in trials IB13-right and left were defleshed around five hours later than the limbs, and the pelvis of trial IB16-right was defleshed nearly five hours earlier than the
fore- and hindlimbs (Table 3-8). However, median cut mark count, cluster area and the standard deviation of cut mark length and area per carcass segment all display virtually no correlation with postmortem time using Pearson’s correlation or Spearman’s rank-order correlation (Table 3-9). Figure 3-43 illustrates this lack of association, which is particularly evident in trials IB13 and IB16-right, where median cluster area changes little despite large increases in postmortem time.

**Discussion**

Cluster attributes were examined on multiple skeletal scales to include all observed cases since in this study outliers represent observed values, not errors in data that should be ignored, and stratification of the cut mark sample into long bone shaft and tool summary scales reduced noise introduced by extreme values. Overall, the greatest differences between cut mark cluster geometry exists among animal size classes, not the experimental factors of tool type or defleshing action.

Cows tended to be butchered with heavier, wider edge tools although samples of tools were not significantly different, and cow trials required significantly more time to complete regardless of the tool type used and the butchery action performed. However, this relationship does not translate directly into cluster abundance, size or the number of cut marks per cluster. In general, cow carcasses tend to have more cut mark clusters, but the unusual abundance of goat scrap defleshing clusters blurs this pattern. Taken together, these differences in treatment conditions support experimental stratification of cow and goat size classes to eliminate any confounding effects that might mask the differences in
cut mark clusters introduced by defleshing actions or tool types. Size class sample stratification also creates the potential for increased detail when predicting the archaeological traces of butchery since differences in carcass processing strategies are expected for animals whose size defines different sets of carcass resources (Lyman, 2005).

Boxplots of cluster attributes grouped by animal size class and butchery action or tool type document the entire sample of multiple mark clusters made in all eight trials of an experimental factor combination, and allow a robust test for different sample medians. In addition to the rarity of differences between butchery action or tool type cluster attributes’ median values within an animal size class, their interquartile ranges usually overlap almost completely. Although occasional differences in tool type or butchery action clusters’ median values were detected, these relationships are not present in either the goat and cow sample.

Further, when differences in cortical surface area and musculo-skeletal anatomy are reduced with a long bone shaft portion scale analysis of cluster attributes, it remains difficult to associate meaningful patterns of cluster size or organization with butchery action or tool type, especially for both goat and cow samples. Differences in cluster attributes between action and tool type categories seem to be randomly patterned across long bone portions. They rarely occur on more than a few portions, and the direction of their difference is often reversed between portions or goat and cow size classes. Unfortunately many of these statistical differences are introduced by the presence of a single cluster during the four butchery trials that comprise an action or tool type sample for each animal size class. While these scarce clusters help define the skeletal locations
that are likely to preserve cut mark traces, they make comparisons of groups medians
difficult, since they do not depict a range of values.

Despite the lack of quantitative difference in cluster attributes that can be used to
identify tool type or defleshing action, comparing cut marks on a bone portion scale
indicates that cut mark cluster geometry is not uniform across the appendicular skeleton.
Therefore it seems that in general, archaeological hypotheses of butchery behavior based
on cut mark data would enjoy increased accuracy when defined for different bone
portions.

Correlations of tool attributes and cluster variables within animal size classes
provide a more detailed glimpse at how tool morphology affects cluster attributes, but at
the expense of the loss of detail when summarizing log transformed values on the entire
appendicular skeleton which may mask variability introduced by anatomical differences.
Regardless, only log tool weight has any strong correlation with cluster attributes on this
scale, but these are only observed in the cow sample. It is also important to keep in mind
that these relationships do not exist as linear correlations in the raw data owing to the
transformation used to force samples closer to normality.

Perhaps investigating differences in either defleshing action or tool type does not
allow a careful enough distinction between clusters made by each tool type during a
particular butchery action. However, discriminant analysis shows this not to be the case.
Log transformed values of cluster attribute pairs predicted to capture the greatest
differences in cut mark organization for distinct defleshing actions or tool types are
accurately classified at a rate only slightly better than chance for single factors, and at
around 25-35% accuracy for the correct butchery action and tool type. This provides little
hope for classifying archaeological cut marks since even in this experimental sample
where defleshing action and tool type are known, significant overlap of cluster attributes
made by each of these treatment factors makes discrimination very difficult.

Therefore, if defleshing action and tool type categories do not produce clusters of
marks that are distinct, perhaps the timing of butchery activities helps explain the
relationship of cluster attributes. However, neither the order in which different forelimbs,
hindlimbs and innominates were butchered or the amount of postmortem time that elapsed before butchery concluded affected cluster attributes in the sample of cow trials.
The experimental butcher reported that tools were more difficult to use as butchery progressed since their edges dulled and adhering fat made them harder to control, but these differences are not recorded in cluster attributes. Likewise, in a few trials, the early stages of rigor mortis stiffened joints, and exposure of skinned carcass segments dried the superficial fascia, but these time-sensitive anatomical changes had only minor effects on the ease of butchery, and were not associated with changes in cut mark cluster geometry.

Cut mark count and length standard deviation are more strongly associated with increasing cluster area than with changes in butchery actions or tool types. This relationship is present in the correlations of all different skeletal scales for both cow and goat size classes. Standard deviation of cut mark angle is most strongly associated with cut mark count, although these linear correlations are relatively weak and not seen in the tool-scale sample for goats. Regardless, it is important to remember that these correlations indicate a pattern in log transformed data that is not linear in the raw data, and that correlation describes an association between measurements of a cut mark cluster, not a causal relationship.
Co-variation of different cut mark attributes is demonstrated in the principal component analysis on log transformed multiple mark clusters. In both goats and cows, all cluster attributes except standard deviation of cut mark angle contribute heavily to the first principle component axis. The second and third components, which together capture nearly all of the sample variance, are controlled primarily by standard deviation of cut mark angle. When these variables are reorganized into linear combinations that express the maximum variability in the sample, discriminant analysis still fails to correctly classify clusters to the appropriate butchery action and tool type.

Comparison with previous ideas about cut mark clusters

The results reported here contradict recent experimental work that suggests bifacially-flaked stone tool edges produce cut mark striae during a single slice that have a more scattered angular orientation (de Juana et al., 2010). In contrast to the intentional slices on dry, defleshed bone surfaces that de Juana et al. used to produce cut marks, this study replicates a more realistic context where skeletons were defleshed of large muscle masses and small scraps. When flesh is butchered from the skeleton, cut mark angle standard deviation per cluster differs more as the size of the cluster increases than across flake and core tool type categories, edge angles or tool weights.

These findings also identify another equifinality that calls into question an archaeological interpretation suggesting Oldowan hominins used handaxes to butcher large animals, particularly hippos at pene-contemporary localities during Okote member times at Koobi Fora, Kenya (Bunn, 1994). As reported here, during butchery of larger
animals, cut mark clusters of larger area are produced, and as larger clusters are produced the standard deviation of cut mark length and angle increase, and that distributions of cut mark angle and length standard deviation are similar for flakes and cores in both goats and cows. Therefore it is difficult to determine whether large clusters of cut marks of uneven length and scattered angular orientation are created by large bifacial stone tools, or whether these patterns are simply a function of large clusters that are typically found on bigger animals. While these data do not preclude the possibility of handaxe butchery, Bunn’s inference is not based on an experimental data set, and the results of this study provide an empirically demonstrated alternative explanation.

Surprisingly, defleshing large bulk muscle units and small scraps at muscle terminations produced indistinguishable clusters of cut marks across most portions of the appendicular skeleton. The defleshing trials in this study realistically replicate meat removal with stone tools prior to consumption, and it was observed that certain skeletal locations, particularly cortical surfaces over which large muscle masses attach or bony landmarks where persistent muscle terminations anchor, were subject to repeated slicing to remove resilient tissue. Therefore it seems likely that clusters of cut marks truly represent the location where slices were necessary to deflesh a bone. Large muscle masses can be defleshed almost completely with very few slices when they are encased in fascia and only terminating tendons need to be severed (e.g. the tibia). In contrast, relatively small scraps of flesh may require numerous filleting slices when they attach broadly over the cortical surface (e.g. the femur). Therefore cut mark location seems to reflect muscular attachment sites, whether they occur over the entire bone shaft or at a tendonous attachment site. Perhaps these observations help explain the curious
similarities in cluster geometry that are common to both bulk and scrap defleshing; cut marks are created when tool slices focus on musculo-skeletal attachment sites, and the same number of slices is necessary to sever the tissue regardless of whether it is a complete muscle or small scrap adhering to its skeletal insertion. This finding mirrors previous experimental studies that document the lack of association between the number of tool strokes and the amount of flesh removed (Egeland, 2003, Pobiner and Braun, 2005).

**Conclusion**

It is typically suggested that differences in butchery behavior will create distinct, interpretable cut mark traces on the skeleton (Binford, 1981, Bunn, 1994, Greenfield, 2006, Nilssen, 2000, Pobiner and Braun, 2005, White, 1992). Specifically, tools that are more difficult to use, like heavier, wider edge bifacial tools, or tools that have dulled during butchery, and butchery actions that require more processing effort like defleshing small muscle scraps from their attachment sites were predicted to affect the size of cut mark clusters, the number of marks and their organization with respect to length and angular orientation. However, the results of this study indicate that the greatest differences among cluster attributes occur between animal size classes, not butchery action or tool type experimental factors, and that increases in the standard deviation of cut mark length and angle are more strongly associated with increasing cut mark count and cluster area than behavioral factors.
Cows and goats have very similar musculo-skeletal anatomy with substantial differences only in size. Not surprisingly, measurements of clusters that reflect size such as cluster area, and median cut mark length per cluster are greater in cows. However, there is no clear relationship between the number of clusters on cows and goats produced in all butchery trials, and cows and goats tend to have a similar number of marks per cluster regardless of tool type or defleshing action. The standard deviation of cut mark length per cluster is higher in the cow sample, but the standard deviation of cut mark angle is not significantly different across size categories. Within each size class for all multiple mark clusters and those occurring on long bone shafts, the standard deviation of cut mark angle has a weak but significant positive correlation with cluster area and cut mark count.

*Appropriately testing zooarchaeological hypotheses*

This study investigates cut mark cluster geometry on three different scales for goats and cows: the butchery factor treatment scale, which examines the distribution of all clusters on the appendicular skeleton from multiple trials, the distribution of clusters on each long bone shaft portion form multiple trials, and cluster summary measurements per tool, which are averaged across each half-carcass trial. These experimental stratifications balance increasing sample size with the loss of analytical detail as cut marks on different parts of the skeleton are summarized. Each stratification contributes important information about how the amount of flesh and type of tool impact the
organization of cut marks in clusters and is most appropriately used to define and test zooarchaeological hypotheses on a corresponding scale.

On the complete skeleton, representing the distribution of all clusters in a treatment category depicts the range of possible cluster attributes, but the results presented here demonstrate that defleshing actions and tool type clusters cannot be distinguished. This scale is suited for addressing hypotheses of archaeological bone modification summarized on an assemblage scale, where fragmentation and specimen disassociation make element and portion identification impossible or inexact.

Examining cut mark clusters per bone portion shows that both bulk and scrap muscle defleshing introduce cut marks onto long bone midshaft portions, contradicting the idea that these marks exclusively represent removal of large muscle masses (Bunn, 2001, Dominguez-Rodrigo, 1999), and that cluster area, cut mark count, and angle and length standard deviation cannot be used to identify the amount of flesh removed from midshafts. Likewise flake versus core butchery marks cannot be reliably distinguished on individual bone portions. This fine anatomical scale allows comparisons of defleshing action and tool type clusters that are not confounded by musculo-skeletal differences between portions. This analysis is useful for testing zooarchaeological hypotheses that also define butchery traces for distinct element and portion categories.

Summarizing cluster attributes per tool calculates the mean value of log-transformed data for each half-carcass trial. It is less inclusive than the butchery factor treatment scale since it only examines clusters form one half-carcass trial, and it averages cut mark attributes over diverse elements and portions. In the data presented here, this scale of analysis demonstrates that tool weight is associated with increasing cluster area,
cut mark count, and standard deviation of cut mark angle in cow trials, but not goat trials, and tool edge angle had no relationship with cluster attributes. This scale of analysis is appropriate for addressing zooarchaeological hypotheses of butchery defined for multiple bones of an individual animal.

We can never directly observe the behavior that generated ancient archaeological assemblages, and following the tradition of middle-range research, the most probable zooarchaeological explanations are supported with arguments drawn from actualistic datasets that aim for precision and realism (Binford, 1981, Capaldo, 1997). Gifford-Gonzalez (1991) outlined a nested hierarchy of inference to connect archaeological traces with the behaviors that created them. Her sequence of inferences requires causal linkages between cut mark traces and effectors (stone tools) before higher-range behavioral and ecological interpretations can be supported. Unfortunately this study suggests that it is unlikely that flake and core tools’ butchery marks can be distinguished and it is equally unlikely that cut mark clusters across the skeleton can be used to conclusively read the amount of muscle tissue present when defleshing began. However, the results presented in this chapter indicate that archaeological conclusions based on cut mark organization within clusters can be attributed to changes in cluster size and differences introduced when butchering large and small animals.

In addition to building a secure chain of inferences to interpret past behavior, this study echoes a recent review of quantitative faunal analysis suggesting that the experimental data used to test an archaeological argument must match in character and scale (Lyman, 2008). Previous butchery experiments that model cut mark traces in too abstract a context (e.g. de Juana et al., 2010, Greenfield, 2006) exclude the contextual
factors encountered during real butchery and therefore create samples of experimental cut marks that are not realistic.
Figure 3-1. Box and whisker plots show the distribution of experimental tool edge angle in degrees across animal size class, defleshing action, and tool type factor categories. The box represents the interquartile range (IQR), which included the middle 50% of observations, the whiskers include the most extreme value within +/- 1.5 times the IQR, and outlying values beyond the whiskers are represented with ‘+’ symbols. The notch around the median is a visual assessment of the Kruskal-Wallis test for different medians. When notches do not overlap in a plot, medians are significantly different at p=0.05.
Figure 3-2. Distribution of experimental tool weight in grams across animal size class, defleshing action, and tool type factor categories.
Figure 3-3. Example cut mark cluster mold. A) 10 millimeter scale. B) Transverse direction of cluster on original bone specimen. C) Each cut mark was traced in pencil on the mold and drawn as a line in ImageJ. D) For curved cut marks, a straight line that best describes the mark trajectory was overlain. E) Cluster perimeter was drawn through cut mark end points that define the minimum cluster area.
Figure 3-4. Distributions of butchery time in minutes per trial across treatment categories.

Figure 3-5. Distributions of cut mark count per cluster across animal size class and defleshing action categories.
Figure 3-6. Distributions of cut mark count in multiple mark clusters across animal size class and defleshing action categories.

Figure 3-7. Distributions of cut mark count per cluster across animal size class and tool type categories.
Figure 3-8. Distributions of cut mark count in multiple mark clusters across animal size class and tool type categories.
Figure 3.9. Distributions of cut mark count per cluster comparing defleshing across cow long bone shaft portions.

Figure 3.10. Distribution of cut mark count per cluster comparing defleshing across goat long bone shaft portions.
Figure 3-11. Distributions of cut mark count per cluster comparing tool types on cow long bone shaft portions.

Figure 3-12. Distributions of cut mark count per cluster comparing tool types on goat long bone shaft portions.
Figure 3-13. Cluster area (mm$^2$) distributions across animal size and defleshing action categories.

Figure 3-14. Cluster area (mm$^2$) distributions across animal size and tool type categories.
Figure 3-15. Cluster area (mm²) distributions comparing defleshing actions on cow long bone shaft portions.

Figure 3-16. Cluster area (mm²) distributions comparing defleshing actions on goat long bone shaft portions.
Figure 3-17. Cluster area (mm$^2$) distributions comparing tool types on cow long bone shaft portions.

Figure 3-18. Cluster area (mm$^2$) distributions comparing tool types on goat long bone shaft portions.
Figure 3-19. Singleton cut mark length (mm) distributions across animal size and defleshing action categories.

Figure 3-20. Singleton cut mark length (mm) distributions across animal size and tool type categories.
Figure 3-21. Distributions of median cut mark length (mm) per multiple mark cluster across animal size and defleshing action categories.

Figure 3-22. Distributions of median cut mark length (mm) per multiple mark cluster across animal size and tool type categories.
Figure 3-23. Distributions of median cut mark length (mm) per multiple mark cluster comparing defleshing actions on cow long bone portions.

Figure 3-24. Distributions of median cut mark length (mm) per multiple mark cluster comparing defleshing actions on goat long bone portions.
Figure 3-25. Distributions of median cut mark length (mm) per multiple mark cluster comparing tool types on cow long bone portions.

Figure 3-26. Distributions of median cut mark length (mm) per multiple mark cluster comparing defleshing actions on goat long bone portions.
Figure 3-27. Distribution of cut mark length standard deviation (mm) per multiple mark cluster across animal size and defleshing actions.

Figure 3-28. Distribution of cut mark length standard deviation (mm) per multiple mark cluster across animal size and tool types.
Figure 3-29. Distribution of cut mark length standard deviation (mm) per multiple mark cluster comparing defleshing actions on cow long bone shaft portions.

Figure 3-30. Distribution of cut mark length standard deviation (mm) per multiple mark cluster comparing defleshing actions on goat long bone shaft portions.
Figure 3-31. Distribution of cut mark length standard deviation (mm) per multiple mark cluster comparing tool types on cow long bone shaft portions.

Figure 3-32. Distribution of cut mark length standard deviation (mm) per multiple mark cluster comparing tool types on goat long bone shaft portions.
Figure 3.33. Distribution of standard deviation of cut mark angle (degrees) per multiple mark cluster across animal size and defleshing action categories.

Figure 3.34. Distribution of standard deviation of cut mark angle (degrees) per multiple mark cluster across animal size and tool type categories.
Figure 3-35. Distribution of standard deviation of cut mark angle (degrees) per multiple mark cluster comparing defleshing actions on cow long bone portions.

Figure 3-36. Distribution of standard deviation of cut mark angle (degrees) per multiple mark cluster comparing defleshing actions on goat long bone portions.
Figure 3-37. Distribution of standard deviation of cut mark angle (degrees) per multiple mark cluster comparing tool types on cow long bone portions.

Figure 3-38. Distribution of standard deviation of cut mark angle (degrees) per multiple mark cluster comparing defleshing actions on goat long bone portions.
Figure 3-39. Scatter plot of the first two principal component scores in the cow multiple mark cluster sample.

Figure 3-40. Scatter plot of the first two principal component scores in the cow multiple mark cluster sample.
Figure 3-41. Distributions of cluster attributes across cow carcass segments.
Figure 3-42. Distributions of cluster attributes across cow carcass segments.

Figure 3-43. Scatter plot of postmortem time versus cluster area per carcass segment listed by trial.
Table 3-1. Experimental defleshing trials organized by treatment category. Edge angle is measured in degrees, tool weight in grams, and elapsed butchery time in minutes. *Multiple mark cluster count shown with singleton cluster count in parentheses.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Side</th>
<th>Size</th>
<th>Action</th>
<th>Tool ID</th>
<th>Tool Type</th>
<th>Raw Material</th>
<th>Edge Angle</th>
<th>Tool Weight</th>
<th>Time</th>
<th>Cluster Count*</th>
</tr>
</thead>
<tbody>
<tr>
<td>IB12</td>
<td>R</td>
<td>cow</td>
<td>bulk</td>
<td>C40</td>
<td>core</td>
<td>chert</td>
<td>50</td>
<td>453.0</td>
<td>39</td>
<td>70 (20)</td>
</tr>
<tr>
<td>IB15</td>
<td>R</td>
<td>cow</td>
<td>bulk</td>
<td>C41</td>
<td>core</td>
<td>chert</td>
<td>60</td>
<td>96.5</td>
<td>38</td>
<td>32 (13)</td>
</tr>
<tr>
<td>IB12</td>
<td>L</td>
<td>cow</td>
<td>scrap</td>
<td>F50-9</td>
<td>core</td>
<td>chert</td>
<td>42</td>
<td>26.1</td>
<td>52</td>
<td>53 (17)</td>
</tr>
<tr>
<td>IB15</td>
<td>L</td>
<td>cow</td>
<td>scrap</td>
<td>F40-4</td>
<td>core</td>
<td>chert</td>
<td>38</td>
<td>39.9</td>
<td>46</td>
<td>37 (10)</td>
</tr>
<tr>
<td>IB13</td>
<td>R</td>
<td>cow</td>
<td>scrap</td>
<td>C37</td>
<td>core</td>
<td>chert</td>
<td>45</td>
<td>731.1</td>
<td>28</td>
<td>50 (17)</td>
</tr>
<tr>
<td>IB16</td>
<td>L</td>
<td>cow</td>
<td>scrap</td>
<td>C42</td>
<td>core</td>
<td>chert</td>
<td>56</td>
<td>102.8</td>
<td>31</td>
<td>36 (24)</td>
</tr>
<tr>
<td>IB13</td>
<td>R</td>
<td>cow</td>
<td>scrap</td>
<td>F83</td>
<td>core</td>
<td>chert</td>
<td>32</td>
<td>5.2</td>
<td>31</td>
<td>42 (30)</td>
</tr>
<tr>
<td>IB16</td>
<td>R</td>
<td>cow</td>
<td>scrap</td>
<td>F70-1</td>
<td>core</td>
<td>chert</td>
<td>67</td>
<td>38.8</td>
<td>26</td>
<td>43 (31)</td>
</tr>
<tr>
<td>IB13</td>
<td>L</td>
<td>goat</td>
<td>scrap</td>
<td>C35</td>
<td>core</td>
<td>chert</td>
<td>43</td>
<td>24.5</td>
<td>25</td>
<td>30 (6)</td>
</tr>
<tr>
<td>IB16</td>
<td>L</td>
<td>goat</td>
<td>scrap</td>
<td>C42</td>
<td>core</td>
<td>chert</td>
<td>20</td>
<td>6</td>
<td>6</td>
<td>6 (6)</td>
</tr>
<tr>
<td>IB10</td>
<td>R</td>
<td>goat</td>
<td>scrap</td>
<td>F92</td>
<td>flake</td>
<td>phonolite</td>
<td>36</td>
<td>65.1</td>
<td>15</td>
<td>38 (25)</td>
</tr>
<tr>
<td>IB9</td>
<td>R</td>
<td>goat</td>
<td>scrap</td>
<td>F71</td>
<td>flake</td>
<td>ignimbrite</td>
<td>16</td>
<td>8.8</td>
<td>19</td>
<td>43 (16)</td>
</tr>
</tbody>
</table>

Table 3-2. Pearson’s correlation values for tool attributes and butchery time per trial.

<table>
<thead>
<tr>
<th>COW corr of edge angle and mean log per tool (N = 8 obs)</th>
<th>cm count</th>
<th>area</th>
<th>med length</th>
<th>std length</th>
<th>std angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>r</td>
<td>0.0523</td>
<td>0.1335</td>
<td>0.2179</td>
<td>0.3237</td>
<td>-0.0453</td>
</tr>
<tr>
<td>p</td>
<td>0.9021</td>
<td>0.7527</td>
<td>0.6042</td>
<td>0.4342</td>
<td>0.9152</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GOAT corr of edge angle and mean log per tool (N = 5 obs)</th>
<th>cm count</th>
<th>area</th>
<th>med length</th>
<th>std length</th>
<th>std angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>r</td>
<td>0.2050</td>
<td>0.4001</td>
<td>0.0556</td>
<td>-0.0063</td>
<td>0.7552</td>
</tr>
<tr>
<td>p</td>
<td>0.7408</td>
<td>0.5046</td>
<td>0.9293</td>
<td>0.9919</td>
<td>0.1399</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>COW corr of log weight and mean log per tool (N = 8 obs)</th>
<th>cm count</th>
<th>area</th>
<th>med length</th>
<th>std length</th>
<th>std angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>r</td>
<td>0.7841</td>
<td>0.7764</td>
<td>-0.2033</td>
<td>0.5950</td>
<td>0.7270</td>
</tr>
<tr>
<td>p</td>
<td><strong>0.0212</strong></td>
<td><strong>0.0235</strong></td>
<td>0.6291</td>
<td>0.1197</td>
<td><strong>0.0410</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GOAT corr of log weight and mean log per tool (N = 5 obs)</th>
<th>cm count</th>
<th>area</th>
<th>med length</th>
<th>std length</th>
<th>std angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>r</td>
<td>0.0967</td>
<td>0.5188</td>
<td>0.7179</td>
<td>0.5032</td>
<td>-0.0962</td>
</tr>
<tr>
<td>p</td>
<td>0.8771</td>
<td>0.3704</td>
<td>0.1721</td>
<td>0.3874</td>
<td>0.8778</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>corr of COW butchery time and mean log per tool (N = 8 obs)</th>
<th>cm count</th>
<th>area</th>
<th>med length</th>
<th>std length</th>
<th>std angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>r</td>
<td>0.2037</td>
<td>-0.0004</td>
<td>-0.0827</td>
<td>0.2611</td>
<td>0.0570</td>
</tr>
<tr>
<td>p</td>
<td>0.6285</td>
<td>0.9992</td>
<td>0.8456</td>
<td>0.5323</td>
<td>0.8933</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>corr of GOAT butchery time and mean log per tool (N = 7 obs)</th>
<th>cm count</th>
<th>area</th>
<th>med length</th>
<th>std length</th>
<th>std angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>r</td>
<td>-0.3306</td>
<td>-0.2147</td>
<td>-0.0210</td>
<td>-0.0534</td>
<td>-0.1118</td>
</tr>
<tr>
<td>p</td>
<td>0.4689</td>
<td>0.6439</td>
<td>0.9644</td>
<td>0.9094</td>
<td>0.8114</td>
</tr>
</tbody>
</table>
Table 3-3. Cluster count across experimental treatment categories.

<table>
<thead>
<tr>
<th></th>
<th>Core*</th>
<th>Flake*</th>
<th>Grand Total*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cow</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulk</td>
<td>102 (33)</td>
<td>90 (27)</td>
<td>192 (60)</td>
</tr>
<tr>
<td>Scrap</td>
<td>86 (41)</td>
<td>85 (61)</td>
<td>171 (102)</td>
</tr>
<tr>
<td><strong>Cow Total</strong></td>
<td>188 (74)</td>
<td>175 (88)</td>
<td>363 (162)</td>
</tr>
<tr>
<td><strong>Goat</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulk</td>
<td>36 (12)</td>
<td>44 (19)</td>
<td>80 (31)</td>
</tr>
<tr>
<td>Scrap</td>
<td>91 (25)</td>
<td>81 (41)</td>
<td>172 (66)</td>
</tr>
<tr>
<td><strong>Goat Total</strong></td>
<td>127 (37)</td>
<td>125 (60)</td>
<td>252 (97)</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td>315 (111)</td>
<td>300 (148)</td>
<td>615 (259)</td>
</tr>
</tbody>
</table>

* Multiple mark clusters. Singleton clusters in parentheses.

Table 3-4. Cluster count per long bone portion across experimental treatment categories. Note that each defleshing action counts clusters made by both tool types and vice versa.

<table>
<thead>
<tr>
<th>Size</th>
<th>Bone ID</th>
<th>Portion ID</th>
<th>Bulk Total</th>
<th>Scrap Total</th>
<th>Core total</th>
<th>Flake total</th>
<th>Grand Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cow</td>
<td>Humerus</td>
<td>PNEF</td>
<td>10</td>
<td>8</td>
<td>5</td>
<td>13</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MSH</td>
<td>13</td>
<td>11</td>
<td>15</td>
<td>9</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DNEF</td>
<td>5</td>
<td>11</td>
<td>2</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Radius</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PNEF</td>
<td>10</td>
<td>9</td>
<td>8</td>
<td>11</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MSH</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ulna</td>
<td>11</td>
<td>7</td>
<td>11</td>
<td>7</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>olecranon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Femur</td>
<td>3</td>
<td>7</td>
<td>5</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PNEF</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MSH</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DNEF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tibia</td>
<td>5</td>
<td>3</td>
<td>8</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PNEF</td>
<td>14</td>
<td>9</td>
<td>12</td>
<td>11</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MSH</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DNEF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Goat</td>
<td>Humerus</td>
<td>PNEF</td>
<td>1</td>
<td>9</td>
<td>5</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MSH</td>
<td>6</td>
<td>8</td>
<td>6</td>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DNEF</td>
<td>3</td>
<td>6</td>
<td>4</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Radius</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PNEF</td>
<td>7</td>
<td>7</td>
<td>6</td>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MSH</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DNEF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ulna</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>olecranon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Femur</td>
<td>1</td>
<td>13</td>
<td>6</td>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PNEF</td>
<td>6</td>
<td>15</td>
<td>9</td>
<td>12</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MSH</td>
<td>4</td>
<td>8</td>
<td>8</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DNEF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tibia</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>6</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PNEF</td>
<td>10</td>
<td>8</td>
<td>7</td>
<td>11</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MSH</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DNEF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cow Total</strong></td>
<td>90</td>
<td>77</td>
<td>81</td>
<td>86</td>
<td>167</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Goat Total</strong></td>
<td>49</td>
<td>89</td>
<td>63</td>
<td>75</td>
<td>138</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td>139</td>
<td>166</td>
<td>144</td>
<td>161</td>
<td>305</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3-5. Pearson’s correlation values for log transformed multiple mark cluster attributes. P values are listed below the diagonal and r values are listed above the diagonal. Significant r values are shown in boldface.

**COW multiple mark clusters**

<table>
<thead>
<tr>
<th></th>
<th>log cm count</th>
<th>log area</th>
<th>log med length</th>
<th>log std length</th>
<th>log std angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>log cm count</td>
<td>0.7041</td>
<td>-0.0039</td>
<td>0.3633</td>
<td>0.4425</td>
<td></td>
</tr>
<tr>
<td>log area</td>
<td>0.0000</td>
<td>0.5576</td>
<td>0.6879</td>
<td>0.2765</td>
<td></td>
</tr>
<tr>
<td>log med length</td>
<td>0.9402</td>
<td>0.0000</td>
<td>0.6634</td>
<td>-0.1493</td>
<td></td>
</tr>
<tr>
<td>log std length</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0105</td>
<td></td>
</tr>
<tr>
<td>log std angle</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0044</td>
<td>0.8419</td>
<td></td>
</tr>
</tbody>
</table>

**GOAT multiple mark clusters**

<table>
<thead>
<tr>
<th></th>
<th>log cm count</th>
<th>log area</th>
<th>log med length</th>
<th>log std length</th>
<th>log std angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>log cm count</td>
<td>0.7392</td>
<td>0.0713</td>
<td>0.4379</td>
<td>0.3404</td>
<td></td>
</tr>
<tr>
<td>log area</td>
<td>0.0000</td>
<td>0.5917</td>
<td>0.6977</td>
<td>0.2589</td>
<td></td>
</tr>
<tr>
<td>log med length</td>
<td>0.2596</td>
<td>0.0000</td>
<td>0.6514</td>
<td>-0.1400</td>
<td></td>
</tr>
<tr>
<td>log std length</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0779</td>
<td></td>
</tr>
<tr>
<td>log std angle</td>
<td>0.0000</td>
<td>0.0263</td>
<td>0.2179</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**COW LB SH clusters**

<table>
<thead>
<tr>
<th></th>
<th>log cm count</th>
<th>log area</th>
<th>log med length</th>
<th>log std length</th>
<th>log std angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>log cm count</td>
<td>0.7603</td>
<td>-0.1238</td>
<td>0.3271</td>
<td>0.4353</td>
<td></td>
</tr>
<tr>
<td>log area</td>
<td>0.0000</td>
<td>0.3266</td>
<td>0.5916</td>
<td>0.2922</td>
<td></td>
</tr>
<tr>
<td>log med length</td>
<td>0.1108</td>
<td>0.0000</td>
<td>0.5407</td>
<td>-0.1917</td>
<td></td>
</tr>
<tr>
<td>log std length</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>-0.0238</td>
<td></td>
</tr>
<tr>
<td>log std angle</td>
<td>0.0000</td>
<td>0.0131</td>
<td>0.7598</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**GOAT LB SH clusters**

<table>
<thead>
<tr>
<th></th>
<th>log cm count</th>
<th>log area</th>
<th>log med length</th>
<th>log std length</th>
<th>log std angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>log cm count</td>
<td>0.8017</td>
<td>0.0087</td>
<td>0.4508</td>
<td>0.3613</td>
<td></td>
</tr>
<tr>
<td>log area</td>
<td>0.0000</td>
<td>0.4514</td>
<td>0.6348</td>
<td>0.2963</td>
<td></td>
</tr>
<tr>
<td>log med length</td>
<td>0.9190</td>
<td>0.0000</td>
<td>0.5611</td>
<td>-0.1958</td>
<td></td>
</tr>
<tr>
<td>log std length</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0759</td>
<td></td>
</tr>
<tr>
<td>log std angle</td>
<td>0.0000</td>
<td>0.0214</td>
<td>0.3764</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**COW mean per tool for log multiple clus value**

<table>
<thead>
<tr>
<th></th>
<th>cm count</th>
<th>area</th>
<th>med length</th>
<th>std length</th>
<th>log std angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>cm count</td>
<td>0.8632</td>
<td>-0.3464</td>
<td>0.6285</td>
<td>0.9536</td>
<td></td>
</tr>
<tr>
<td>area</td>
<td>0.0058</td>
<td>0.1179</td>
<td>0.8291</td>
<td>0.8712</td>
<td></td>
</tr>
<tr>
<td>med length</td>
<td>0.4006</td>
<td>0.7810</td>
<td>0.4551</td>
<td>-0.3152</td>
<td></td>
</tr>
<tr>
<td>std length</td>
<td>0.0951</td>
<td>0.0109</td>
<td>0.2572</td>
<td>0.5278</td>
<td></td>
</tr>
<tr>
<td>std angle</td>
<td>0.0002</td>
<td>0.0048</td>
<td>0.4469</td>
<td>0.1788</td>
<td></td>
</tr>
</tbody>
</table>

**GOAT mean per tool for log multiple clus value**

<table>
<thead>
<tr>
<th></th>
<th>cm count</th>
<th>area</th>
<th>med length</th>
<th>std length</th>
<th>log std angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>cm count</td>
<td>0.9730</td>
<td>0.7025</td>
<td>0.8779</td>
<td>0.3343</td>
<td></td>
</tr>
<tr>
<td>area</td>
<td>0.0000</td>
<td>0.7956</td>
<td>0.9377</td>
<td>0.3788</td>
<td></td>
</tr>
<tr>
<td>med length</td>
<td>0.0520</td>
<td>0.0182</td>
<td>0.8842</td>
<td>0.0487</td>
<td></td>
</tr>
<tr>
<td>std length</td>
<td>0.0041</td>
<td>0.0006</td>
<td>0.0036</td>
<td>0.1354</td>
<td></td>
</tr>
<tr>
<td>std angle</td>
<td>0.4183</td>
<td>0.3548</td>
<td>0.9088</td>
<td>0.7491</td>
<td></td>
</tr>
</tbody>
</table>
Table 3-6. Principal component analysis results on standardized, log transformed multiple mark cluster attributes.

<table>
<thead>
<tr>
<th></th>
<th>COW</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>variances</th>
<th>% explained</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pc1</td>
<td>pc2</td>
<td>pc3</td>
<td>pc4</td>
<td>pc5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cm count</td>
<td>0.4294</td>
<td>-0.4772</td>
<td>0.5260</td>
<td>-0.1046</td>
<td>0.5480</td>
<td>pc1</td>
<td>2.5941</td>
</tr>
<tr>
<td>area</td>
<td>0.5882</td>
<td>-0.0575</td>
<td>0.1217</td>
<td>-0.3810</td>
<td>-0.7005</td>
<td>pc2</td>
<td>1.4726</td>
</tr>
<tr>
<td>med length</td>
<td>0.4040</td>
<td>0.5291</td>
<td>-0.4095</td>
<td>-0.4255</td>
<td>0.4561</td>
<td>pc3</td>
<td>0.5544</td>
</tr>
<tr>
<td>std length</td>
<td>0.5210</td>
<td>0.2780</td>
<td>0.0104</td>
<td>0.8066</td>
<td>-0.0222</td>
<td>pc4</td>
<td>0.2794</td>
</tr>
<tr>
<td>std angle</td>
<td>0.1868</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>pc5</td>
<td>0.0994</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GOAT</td>
<td>pc1</td>
<td>pc2</td>
<td>pc3</td>
<td>pc4</td>
<td>pc5</td>
<td>variances</td>
<td>% explained</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cm count</td>
<td>-0.4416</td>
<td>0.4309</td>
<td>-0.5807</td>
<td>0.0611</td>
<td>0.5276</td>
<td>pc1</td>
<td>2.6841</td>
</tr>
<tr>
<td>area</td>
<td>-0.5799</td>
<td>0.0579</td>
<td>-0.1192</td>
<td>0.3809</td>
<td>-0.7078</td>
<td>pc2</td>
<td>1.3228</td>
</tr>
<tr>
<td>med length</td>
<td>-0.4102</td>
<td>-0.5434</td>
<td>0.3725</td>
<td>0.4306</td>
<td>0.4607</td>
<td>pc3</td>
<td>0.6142</td>
</tr>
<tr>
<td>std length</td>
<td>-0.5216</td>
<td>-0.2223</td>
<td>0.1030</td>
<td>-0.8159</td>
<td>-0.0472</td>
<td>pc4</td>
<td>0.2971</td>
</tr>
<tr>
<td>std angle</td>
<td>-0.1684</td>
<td>0.6828</td>
<td>0.7066</td>
<td>0.0063</td>
<td>0.0783</td>
<td>pc5</td>
<td>0.0819</td>
</tr>
</tbody>
</table>
Table 3-7. Error rates from linear discriminant analyses on log transformed cluster variable pairs for all multiple mark clusters, long bone shaft clusters, and on the first 3 principle component scores in the multiple mark cluster sample.

### Multiple mark clusters

<table>
<thead>
<tr>
<th></th>
<th>COW</th>
<th>GOAT</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cm count and area</td>
<td>std len and area</td>
<td>std angle and area</td>
<td>med len and std angle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>action</td>
<td>0.434</td>
<td>0.474</td>
<td>0.469</td>
<td>0.496</td>
<td></td>
<td></td>
</tr>
<tr>
<td>tool type</td>
<td>0.431</td>
<td>0.452</td>
<td>0.437</td>
<td>0.443</td>
<td></td>
<td></td>
</tr>
<tr>
<td>action x tool type</td>
<td>0.662</td>
<td>0.719</td>
<td>0.662</td>
<td>0.688</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### GOAT

<table>
<thead>
<tr>
<th></th>
<th>COW</th>
<th>GOAT</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cm count and area</td>
<td>std len and area</td>
<td>std angle and area</td>
<td>med len and std angle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>action</td>
<td>0.451</td>
<td>0.525</td>
<td>0.492</td>
<td>0.446</td>
<td></td>
<td></td>
</tr>
<tr>
<td>tool type</td>
<td>0.528</td>
<td>0.480</td>
<td>0.492</td>
<td>0.460</td>
<td></td>
<td></td>
</tr>
<tr>
<td>action x tool type</td>
<td>0.707</td>
<td>0.741</td>
<td>0.727</td>
<td>0.660</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### LB SH clusters

<table>
<thead>
<tr>
<th></th>
<th>COW</th>
<th>GOAT</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cm count and area</td>
<td>std len and area</td>
<td>std angle and area</td>
<td>med len and std angle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>action</td>
<td>0.418</td>
<td>0.463</td>
<td>0.450</td>
<td>0.444</td>
<td></td>
<td></td>
</tr>
<tr>
<td>tool type</td>
<td>0.421</td>
<td>0.448</td>
<td>0.424</td>
<td>0.453</td>
<td></td>
<td></td>
</tr>
<tr>
<td>action x tool type</td>
<td>0.652</td>
<td>0.734</td>
<td>0.676</td>
<td>0.697</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### DFA on first 3 PC scores for multiple mark clusters

<table>
<thead>
<tr>
<th></th>
<th>COW</th>
<th>GOAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>action</td>
<td>0.4407</td>
<td>0.4513</td>
</tr>
<tr>
<td>tool type</td>
<td>0.4192</td>
<td>0.4527</td>
</tr>
<tr>
<td>action x tool type</td>
<td>0.6774</td>
<td>0.6495</td>
</tr>
</tbody>
</table>
Table 3-9. Correlation analysis for postmortem time and median cluster value per carcass segment.

<table>
<thead>
<tr>
<th>Pearson</th>
<th>cm count</th>
<th>area</th>
<th>std length</th>
<th>std angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>r</td>
<td>-0.0945</td>
<td>-0.2091</td>
<td>0.0142</td>
<td>-0.1375</td>
</tr>
<tr>
<td>p</td>
<td>0.6606</td>
<td>0.3267</td>
<td>0.9477</td>
<td>0.5217</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Spearman</th>
<th>cm count</th>
<th>area</th>
<th>std length</th>
<th>std angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>r</td>
<td>-0.0922</td>
<td>-0.3358</td>
<td>-0.0670</td>
<td>-0.2327</td>
</tr>
<tr>
<td>p</td>
<td>0.6684</td>
<td>0.1087</td>
<td>0.7558</td>
<td>0.2738</td>
</tr>
</tbody>
</table>
Chapter 4:

Modeling ecologically informative butchery traces

Abstract

Current archaeological analysis of hominin carnivory infers early or late hominin access to carcasses with data generated in sequential actualistic models that specify the proportions of cut, percussion, and carnivore tooth-marked fragmentary bone specimens in experimental assemblages (Blumenschine, 1988, 1995, Capaldo, 1995, 1997, 1998, Dominguez-Rodrigo, 1997, Selvaggio, 1998). These models generated important information about the skeletal traces of human and carnivore defleshing and fragmentation, but archaeological comparisons with these models can be compromised since the proportion of modified specimens in an archaeological assemblages is influenced by both post-depositional fragmentation and fragmentation during marrow consumption (Pickering and Egeland, 2006). Likewise considering cut marks as a general class of butchery evidence masks the behavioral variability of cut marks that are created during skinning, disarticulation, and defleshing. Cut marks from these actions occur at distinct skeletal landmarks and can be used to build hypotheses of butchery action sequences reflecting early and late access to carcasses resources. Distinguishing experimental disarticualtion and defleshing cut mark clusters on goat and cow elbow portions provides another line of evidence for interpreting archaeological butchery of complete versus defleshed carcasses.
Introduction

This chapter outlines a new technique for interpreting the carnivorous ecological role of *Homo erectus* from butchered bone assemblages in Okote Member deposits at Koobi Fora. This technique is designed with the nature of these assemblages in mind; they are highly fragmented with few long bone ends, but have excellent surface preservation with an abundance of hominin butchery traces and relatively few carnivore tooth marks (Pobiner, 2007, Pobiner *et al.*, 2008). While this method is designed with a specific archaeological dataset in mind, its central concept can be generalized to construct a zooarchaeological interpretation of butchery evidence in diverse geographic, temporal and paleoecological contexts.

To begin the conceptual development of this archaeological model, existing paleoecological models of hominin carnivory are reviewed, focusing specifically on the polarized ecological reconstructions introduced by the hunting versus scavenging debate (Lee and deVore, 1968), and the complex layers of inference and empirical justifications that are necessary to support realistic paleoecological arguments (e.g. Binford, 1981, Gifford-Gonzalez, 1991). Actualistic models of sequential carcass consumption that provide the current analytical framework for evaluating the archaeological traces of carnivory in zooarchaeological assemblages are also reviewed (e.g. Blumenschine, 1995, Capaldo, 1998, Dominguez-Rodrigo, 1999, Selvaggio, 1998). This chapter builds on the information generated by these models and attempts to increase the precision of paleoecological reconstructions of hominin carnivory drawn from butchered bone
assemblages by evaluating the ecological contexts of butchery traces interpreted on individual specimens.

To build a testable hypothetical model of Okote hominin carnivory, this chapter draws evidence from actualistic butchery studies presented in chapters 2 and 3 of this dissertation. As they show, it is not possible to determine the amount of flesh removed from a limb by examining a cut mark’s cross section or the geometric organization of a cut mark cluster. Therefore it is not possible to build a general quantitative model of cut mark attributes for the entire skeleton and for animals in different size classes against which inferences about early or late hominin carcass access can be examined, especially on archaeological bone fragments that cannot be identified to skeletal element or portion. Rather a more focused interpretive approach is suggested. Experimental results presented in chapter 2 indicate that skeletal location and cut mark cross-section can be used to distinguish defleshing, disarticulation and skinning cut marks. This chapter adds a discussion of defleshing versus disarticulation cut mark cluster geometry and constructs likely sequences of butchery actions that represent complete consumption of whole carcasses (primary hominin access) and carcasses consumed after other carnivores enjoyed initial access (secondary hominin access). Early and late hominin access to carcasses predict distinct hypothetical sequences of butchery actions. The location and attributes of cut marks produced by these sequences are defined, along with the skeletal portions likely to preserve these traces after carnivore ravaging.

As shown by experimental evidence in this chapter, portions of the elbow joint are differentially cut-marked during defleshing and disarticulation, and these portions commonly survive bone consumer ravaging and density-mediated destruction (Binford,
1978, Marean and Spencer, 1991, Marean et al. 1992). Therefore, even in the absence of traces of secondary hominin carcass access like carnivore defleshing tooth marks, elbow bones that preserve disarticulation cut marks but not defleshing cut marks suggest that hominins had late access to a particular carcass. In fact, carnivores consume elbow flesh relatively late in the carcass consumption sequence, so hominin defleshing cut marks on the elbow do not necessarily reflect primary access to a carcass, highlighting the complexity of ecological inferences drawn from cut mark data. Therefore the interpretive technique described here examines a component of a butchered assemblage in detail, but suggests incorporating assemblage-scale contextual evidence from other taphonomic sources to build multiple lines of evidence for reconstructing ancient tool-assisted carcass consumption (Gifford-Gonzalez, 1991).

Modeling the paleoecology of carcass consumption

Investigating human carnivory is fascinating because it explores the evolving human niche as hominins gained ecological dominance, transitioning from being a prey item to occupying the top ranking position in all terrestrial ecosystems, and it does so by analyzing physical evidence of hominins’ technologically mediated consumption of prey species and interaction with carnivorous competitors.

Secure evidence of butchered bone appears in the archaeological record concurrently with the earliest stone tools (de Heinzelin et al., 1999, Dominguez-Rodrigo et al., 2005, Harris and Capaldo, 1993) but a recent report attempts to push the earliest stone tool assisted carnivory back to 3.4 Ma, implying that stones were used as
rudimentary butchery tools even before Oldowan implements were common enough in the behavioral repertoire to gain archaeological visibility (McPherron et al., 2010). However, it seems more likely that the Dikika specimens’ modifications are not true butchery traces, but were affected by abiotic processes that caused percussion and abrasion marks, and that the ecological interpretations which suggest that *Australopithecus afarensis* transported stone materials for carcass fragmentation are unwarranted (Dominguez-Rodrigo et al., 2010). This recent debate highlights the well-founded referential framework and multiple layers of inference that are necessary to link bone surface marks to hominin agency and to securely infer the ecological contexts in which these traces of carnivory were created.

Hypothesizing likely ecological strategies of hominin carnivory involves observing living primates and carnivores with an eye toward the suggestions of the archaeological and hominin fossil records. Hominins are omnivores, not obligate carnivores, so it is important to keep in mind that we are studying a portion of the dietary ecology of *Homo erectus*. That said, the introduction of carnivory is linked with higher quality diets and encephalization (Leonard and Robertson, 1997, 2000, Aiello and Wheeler, 1995), and is certainly involved in the development and dependence on technological behavior. Recent discovery of alleged butchered bones attributed to *Australopithecus* in Ethiopia and the pounding tool use by certain chimpanzee and capuchin monkey groups (Haslam et al., 2009) highlight the way that technological behavior can open up novel feeding niches. But curiously, this technologically mediated feeding behavior is not a species-wide adaptation for these primates, but a socially transmitted behavioral strategy practiced when specific conditions are met.
However before jumping to evolutionary conclusions, it is important to note that ecological conditions fluctuate on a much shorter time scale than evolutionary changes, and behavioral responses to an ecological context can be even more ephemeral. Therefore, this investigation aims to contribute to our understanding of the evolution of hominin carnivory though careful modeling of the carnivorous foraging strategies practiced by *Homo erectus* during Okote member times at Koobi Fora, Kenya.

Foraging strategies practiced by carnivorous hominins can first be separated into hunting versus scavenging. Hunting is observed in arboreal and terrestrial primate species (Mitani and Watts, 1999, Surbeck and Hohmann, 2008) and in general, the outcome of predator-prey interactions are largely mediated by predator and prey body size and the number of individuals involved in the conflict (Van Valkenburgh, 2001). Scavenging is also a common behavioral strategy of many carnivores that are commonly thought of as primary predators, including felids (Stander 1992, Caro, 1982). Even the Hadza, a hunter-gatherer group that uses ambush hunting techniques and poisoned bow and arrow technology to hunt large mammals commonly scavenge the prey of carnivores (Lupo and O’Connell, 2002, O’Connell *et al.*, 1988). This generalist behavioral flexibility benefits these different carnivores by providing them access to the large packages of nutrients contained in animal carcass resources in a variety of ecological contexts, but this behavioral flexibility it makes it much more difficult for the paleoanthropologists to hypothesize the nature of early human carnivory. It seems likely that *Homo erectus* practiced a variety of foraging strategies, and occupied a liminal position within the trophic hierarchy, shifting between hunter and scavenger. Indeed the zooarchaeological literature has cast early humans in different ecological roles.
But unfortunately for zooarchaeologists, the hypothetical foraging strategies discussed below are subject to equifinality, since all that can be reliably inferred from a butchered bone is whether it was defleshed, disarticulated from its adjacent skeletal element, fragmented by a hammerstone, or fed upon by carnivores. Therefore, the diversity of carnivorous foraging strategies practiced by *Homo erectus* cannot easily be distinguished in the archaeological record, and we are forced to discern whether assemblages of bone represent hominins’ early or late access to carcass resources (Blumenschine, 1986, Selvaggio, 1998). Additionally, when examining archaeological evidence of these foraging behaviors, it is even more difficult to reconstruct which behaviors were habitual foraging strategies or random events that took place whenever the appropriate ecological context presented itself.

**The role of inference in paleoecological interpretations of hominin carnivory**

Gifford-Gonzalez (1991) outlined the theoretical underpinning of most paleoanthropological arguments about ancient ecology with her nested hierarchy of inferences. The static traces of behavior were created in some unknown multiplicity of ancient behavioral and ecological contexts, and the most secure way to connect these traces to their higher range context, is to explore these ancient process-trace relationships by studying carefully designed modern analogues (Binford, 1981). These important ideas originated in an attempt to add strength to inferences about ancient hominin ecology based on the presence of butchery marks and carnivore tooth marks on bone assemblages (Gifford, 1981). Gifford-Gonzalez defined her nested hierarchy of inferences about
ancient behavior as the production of a static trace by an effector, which was wielded by an actor and occurred in a specific behavioral context that was subsumed within a larger ecological context. To illustrate this example, imagine that a cut mark was produced by a stone tool, which was wielded by a hominin during a butchery episode of a scavenged carcass.

The concept of equifinality is central to Gifford-Gonzalez’s analytical framework. As one proceeds up the chain of inference, higher causal processes become more complex, and without increasingly complex modern analogues, which necessitate large samples of observations, it becomes difficult to differentiate which causal process produced a behavioral trace. When multiple causes produce analytically identical traces of behavior, an inference is subject to equifinality. For example, as this dissertation shows, it is possible to determine that cut marks are made during butchery, but it is not possible to distinguish cut marks made when large amounts of flesh are removed from those created during muscle scrap defleshing (see also Egeland, 2003, Pobiner and Braun, 2005), and therefore when looking only at a cut mark, one cannot determine whether a carcass was acquired when complete or scavenged by hominins. This example demonstrates that when equifinality exists in the interpretation of the behavioral context of butchery from cut mark data, it limits conclusions about the ecological context in which a behavioral trace was produced. To eliminate equifinality, Gifford-Gonzalez suggests two techniques: improve the accuracy of inferences about traces of behavior and their context with further experimental modeling, and draw upon multiple lines of evidence to side-step the equifinality. This dissertation follows the first suggestion and attempts to define cut mark signatures of different butchery actions. When suggesting
additional lines of evidence, Gifford-Gonzalez advocates following an entirely different chain of inference to draw conclusions about the behavioral and ecological contexts of hominin carnivory. An example of this is the naturalistic and experimental observations of carcass consumption that were used to describe tooth mark distribution across the skeleton in relation to the amount of meat left for scavenging hominins (Bluemenschine, 1986, 1995, Capaldo, 1998, Dominguez-Rodrigo, 1999, Marean et al., 1992, Pobiner, 2007).

Gifford-Gonzalez also explores the difficulty of modeling the behavioral contexts of butchery with archaeological data. When creating archaeological interpretations with this model one can imagine a line in the three dimensional space of the model, passing thorough the points which represent ecological context, behavioral context, actor, and effector and eventually connecting to a specific trace. This structure works well to establish that cut marks were made by stone tool slices during butchery, or that carnivore consumption creates tooth pits. However, a butchered animal is not a uniform trace fossil and is more difficult to model, especially when additional taphonomic processes introduce additional uncertainty. There is no reason to assume that cut mark traces representing primary hominin meat consumption will be recorded on every bone fragment of a butchered animal.

Although this is the most clearly defined inferential framework, Gifford-Gonzalez’s model does not automatically generate archaeologically testable hypotheses. In fact, additional sets of inferences are necessary to model how fragmentation, scavenger ravaging, and multiple abiotic taphonomic processes that affect bone specimen
preservation and identification influence interpretations of butchery from assemblages of modified bone.

Although Gifford-Gonzalez’s model is abstracted to illustrate the kinds of inferential links that allow archaeological traces to represent behavioral and ecological contexts, these higher-range concepts (Binford, 1981) are not specifically described. The research question defines which specific behavioral and ecological contexts are sought and the chains of inference that are necessary to support them. Likewise it defines the scale of data with which these inferences are appropriately constructed.

Behavioral ecology (Blumenschine et al., 1994, Krebs and Davies, 1997) is the contemporary field that provides theoretical inspiration for the types of questions addressed in the paleoanthropological study of hominin carnivory. However, behavioral ecology experimentally manipulates situations and explains their outcomes in the present day, whereas paleoanthropological investigation of ancient human carnivory evaluates historical evidence (in this case assemblages of butchered bone), and attempts to support inferences about the causal ecological processes that created them. Both fields use a mix of deductive and inductive explanations to generate knowledge, going back and forth between interpreting patterns in data to determine causal processes, and then refining these statements with more rigorous hypothetical tests of causal processes’ operation that are verified by examining data. Behavioral ecological explanations generate high-resolution interpretations because they can control for behavioral and ecological variables in the present day to understand them from a variety of inferential directions. The archaeological interpretation is complicated by the historical context of the data it investigates. Archaeological data are the static remains of past processes, and can only be
studied in modern analogues of past systems (Binford, 1981). Similarly, interpretations of hominin carnivory address only a component of hominins’ diet, foraging behavior and trophic position. We must recognize many aspects of early human paleoecology are archaeologically invisible, but continue to invent novel techniques for making the most secure inferences possible about hominins’ role in extinct ecosystems.

A brief history of paleoecological models of hominin carnivory

Taphonomically informed interpretations of hominin carnivory

The history of the hunting versus scavenging debate defined the extreme ecological roles attributed to early humans when zooarchaeological analysis was a relatively young field and was not yet informed by the critical lens of taphonomy that was introduced the work of C. K. Brain (1967, 1969, 1980). The focus on megafaunal exploitation by *Homo sapiens* in North American prehistory and the interest in this behavior in Europe generated by incredible works of cave art popularized the prehistoric role of ancient people as capable hunters (see Klein, 1999). Around the same time, socially defined gender roles influenced interpretations of ancient life, mapping these cultural ideas about sexual division of labor onto the hunter/gatherer ecological spectrum (Lee and DeVore, 1968).

During this early phase of paleoanthropological inquiry, especially as the South African cave sites yielded the first fossil hominin specimens, the spatial association of hominin fossils and fragmentary animal remains was assumed to represent a behavioral
link, specifically that even in deep prehistory, early humans were hunting animals. At Makapansgat, Dart described the osteodontokeratic bone tool industry, suggesting that Australopithecines used sharp bone fragments for daggers in primitive tribal warfare, scapulae for shovels, and hemi-mandibles for saws (Dart, 1957, 1959, 1960). Critical examination of the non-hominin bone assemblages from these sites was inspired partly by the discovery of additional hominin fossil crania with leopard tooth punctures and raptor talon scores. The marks suggested an alternative explanation for the collections of bones in the South African caves; perhaps these sites were not ancient dwellings filled with the remains of hominin hunting, but hominins were prey to various carnivores like the other fauna deposited in the cave sediments (Brain, 1980).

C. K. Brain was instrumental in demonstrating that carnivore ravaging of animal bones commonly breaks bones into the sharp fragments that Dart mistook for osteodontokeratic weapons (Brain, 1980, 1981). With his work, Brain laid the foundation for the adoption of taphonomic theory in paleoanthropology. The study of burial processes (Efremov, 1940) was previously utilized in paleontology to describe the details of death and preservation in diverse paleobiological contexts including invertebrate accumulations and macrofaunal mass deaths, but Brain highlighted the potential that careful studies of site formation had for clarifying interpretations of ancient human behavior from archaeological remains.

Key to this mode of inquiry is an analytical method that attempts to explain ancient behavior by carefully studying a contemporary realistic model of past processes, and this theoretical paradigm sparked Processual Archaeology (Binford, 1981). With the idea that past processes could be modeled and studied in the present, this stage in the
history of archaeology (also then called the “New” Archaeology) initiated a critical quantitative approach. However, it was also criticized for its suggestion that any past process can be understood with an appropriate modern analog and was characterized as reductionist (Hodder, 1991). But this paradigm generated considerable scientific knowledge, describing the diagnostic traces on fossil bone surfaces that indicate whether specimens were chewed by carnivores, butchered by stone tool wielding hominins for meat or marrow, trampled by passing ungulates, and the length of time a bone laid on the ground surface via weathering stages (Behrensmeyer et al. 1986, Behrensmeyer, 1978, Blumenschine and Selvaggio, 1988, Binford, 1981, Bunn, 1981, Haynes, 1983, Potts, 1981). However, interpreting the higher range contexts within which these traces of behavior originated was problematic and cast early humans in a diversity of ecological roles including capable hunters, aggressive scavengers, passive scavengers, and scavengers of marginal resources (Binford, 1981, Bunn and Kroll, 1986, Bunn and Ezzo, 1993, Blumenschine, 1995).

Central to this debate is FLK Zinjanthropus the largest, best-preserved assemblage of stone tools and butchered bone in the East African Early Pleistocene (Leakey, 1971). It was excavated by Mary Leakey before taphonomically informed archaeology indicated that every bone specimen should be collected, so it is possible that very small butchered bone specimens are missing. Otherwise this assemblage serves as the stage on which the majority of the debate about Early Pleistocene hominin carnivorous ecology takes place.

Zooarchaeologists recognized the difficulty of interpreting hominin behavior in fragmentary bone assemblages modified by sequences of different taphonomic processes
and agents, and designed actualistic experiments and naturalistic observations to model the site formation of the *Zinjanthropus* assemblage (Blumenschine, 1995, Capaldo, 1995, 1998, Dominguez-Rodrigo, 1997, Lupo and O’Connell, 2002, Selvaggio, 1998). These models are discussed in more detail later in this chapter, but in general they focused on determining the order in which hominins had access to carcass resources in the chain of consumers by examining bone surface modification in the assemblage. Still these diverse studies reached no common conclusion about the paleoecological role of early human carnivores.

*Current paleoecological hypotheses of hominin foraging*

Expanding on the realization that hominins were not the sole agent of bone accumulation and modification, various researchers used information gathered in modern ecological observations to build hypotheses detailing the paleoecology of hominin carcass access, in particular, defining different behavioral strategies of scavenging.

Recognizing the importance of prey size and interspecific competition, Bunn and Ezzo proposed a confrontational scavenging model of Early Pleistocene hominin foraging (Bunn and Ezzo, 1993, Bunn, 2001). Here hominins appropriate carnivoran kills by physical intimidation, possibly through throwing rocks or using a group size advantage. Based on the number of primary predator consumers, this strategy could offer a significant meal for hominins. But it seems unlikely that hominins would have much success at acquiring carcasses when they do not possess the body and/or group size advantage.
In contrast to this hypothesis, passive scavenging has also been proposed as a means of carcass access, but with two distinct ecological implications for scavenging abandoned carnivore kills. When carcasses are fully defleshed by flesh-specialists, hominins disarticulate and fracture long bones and crania for their marrow and brains. But as several authors note, carnivores also commonly abandon kills before their flesh is fully consumed (Blumenschine, 1986; Dominguez-Rodrigo, 1999, Selvaggio, 1998). In fact I have observed multiple instances in modern settings where this occurred. For example, figure 4-1 shows a female eland carcass killed by two lions with its right side limb flesh completely consumed, but much of the abdominal viscera, and complete left side remaining with intact flesh. The lions responsible for the kill the previous night were radio collared and determined to be kilometers away, apparently resting with the intention of returning to finish consuming their kill later that evening (Lawrence Frank, personal communication). As detailed actualistic research shows, the amount of flesh and within bone nutrients present on the landscape for scavengers are a function of the competitive outcomes between members of the carnivoran paleoguilds, and are influenced by seasonality, micro-habitat and the relationship of prey size to predator group composition (Blumenschine, 1989, Pobiner, 2007).

Therefore a hominin’s knowledge of their home range most likely influenced their success at acquiring carcass resources from large animals, and idea incorporated into other models of hominin foraging. Binford (1981, 1988) describes a chimp-like ‘feed as you go’ strategy to explain the formation of the FLK Zinjanthropus assemblage. Although this hypothesis is outlined specifically for Homo habilis at Olduvai Gorge, it defines the passive scavenging reconstruction of hominin foraging where individuals
moved over the landscape and broke the long bones of defleshed carnivore kills, butchering them *in situ* or transporting them to secure locations on the landscape (see Isaac, 1983).

Cavallo and Blumenschine (1989) define a similar scavenging niche for hominins ranging over areas with riparian habitat. The tree-stored leopard kill model also describes hominins’ directed foraging across a landscape, but suggests that they repeatedly checked leopard trees for cached carcasses. Based on naturalistic observations, the authors determined that leopard kills were sources of small to medium size carcasses that contained significant amounts of meat and marrow, and were frequently left temporarily abandoned by leopards. Further, these cached kills occurred at known locations on the landscape, and were not likely to be usurped by vultures since they were difficult to see from the air, and other scavengers could not climb to reach them.

Perhaps the academic debate regarding early and late hominin carcass access masks the diversity of behavioral strategies practiced by *Homo erectus*. All of the foraging strategies discussed above are based on modern ecological observations, but the contentious issue is how to determine if they were practiced by *H. erectus*, were recorded archaeologically, and whether these behaviors can be distinguished archaeologically. To be clear about my assumptions that influence the construction of this model, I suggest that *H. erectus* was a carnivorous generalist and accessed carcass resources when they were available, with least effort strategies that skirted the boundary between individual safety and nutritional yield.

*Sequential actualistic models of carcass consumption*
Designed originally to investigate the paleoecological context of the FLK *Zinjanthropus* zooarchaeological assemblage, sequential actualistic models of carcass consumption explore how different sequences of hominin and carnivore carcass consumption create fragmentary bone assemblages with bone surface marks that represent the traces of these agents (Blumenschine, 1988, 1995, Capaldo, 1998, Dominguez-Rodrigo, 1997, Selvaggio, 1998). These models quantified the assemblage-scale proportions of modified specimens expected when hominins had early access to flesh or were restricted to within-bone nutrients in a late access scenario.

Previous archaeological explanations of hominin carnivory focused on skeletal part profiles and were inconclusive with respect to whether head and foot parts represented early hominin marginal scavenging form carnivore kills, the ‘schlep effect’ (Binford, 1984, 1988, Binford and Bertram, 1977, Binford *et al.*, 1988, Binford and Todd, 1982) or that more complete representation of limb parts indicated hominin hunting (Bunn and Kroll, 1986, 1988). One major contributions of the sequential actualistic models was their documentation that carcass consumption including defleshing, marrow exploitation and scavenger ravaging transforms an individual animal into a collection of bone fragments that bear traces of the consumption process (Oliver, 1993, Pickering *et al.*, 2006). These experimental models also show that long bone midshaft portions preserve the clearest glimpse of hominin and carnivore activity since they survive scavenger ravaging which deletes other bone portions.

This information was gathered by simulating sequential hominin and carnivore consumption of carcasses (or half carcass trials) that reflect early or late hominin access
followed by hyena ravaging. Then amongst all trials in a treatment category, the proportion of post-ravaged specimens bearing cut marks, percussion marks or carnivore tooth marks were tallied. This calculation generates the major result of these models: the proportion of bone fragments (often long bone midshafts) in the experimental assemblage bearing a type of bone modification (cut mark, percussion mark or carnivore tooth mark), which represents the order in which hominins and carnivores consumed a carcass. For example when the proportion of fragments bearing tooth marks is high, and low for cut marks, carnivores had early access to flesh, and with the opposite pattern, hominins accessed carcasses early in the consumption sequence.

These models are the subject of much debate for their inter-observer comparability of experimental methods, results, and application to archaeological assemblages (Dominguez-Rodrigo, 2002, Monahan, 1999, O’Connell and Lupo, 2003). In reality, these experimental models satisfy the criteria suggested for using modern analogues to study the past (Capaldo, 1995). They explore realistic models of past systems and generate data that can be applied to the archaeological case they study.

But in reality, much more emphasis was placed on the proportion of cut mark, percussion marked and tooth marked specimens which were the final results of the consumption process, than on documenting the bone modification traces introduced during the sequence of consumption stages. In a sense this is appropriate, because after all, an archaeological assemblage is collection of bone fragments that can never be reconstructed with complete certainty to represent the individual animals whose carcasses or parts were present before butchery and other taphonomic processes removed portions and introduced unidentifiability. But it is exactly this analytical uncertainty that combines
with the other shortcomings discussed below, to weaken the archaeological interpretations generated by sequential actualistic models.

Difficulty in integrating the experimental models of different researchers that study the same process is a major drawback since it reduces the overall sample of observed cases of carcass consumption and bone assemblage formation. Comparability between different models is reduced by the use of different long bone portion categories. These analytical categories are extremely important since they define the discrete categories within which bones unidentifiable to skeletal element are classified, and because they have different mechanical properties, are associated with different nutritional resources, and have different rates of survival during fragmentation. I argue, following Blumenschine (1988, see also Capaldo, 1995), that precision in both skeletal element and long bone portion categories should be maximized because it allows for a more detailed description of carcass modification during consumption.

I suggest a finer analytical distinction that includes skeletal element would improve the resolution of interpretation about the butchery traces documented on different parts of the skeleton. But unfortunately when examining the unidentifiable component of an assemblage the sample of fragments in each long bone portion category is reduced and additional potential sources of error including specimen misidentification and inter-analyst disagreement are introduced, suggesting that this level of detail is problematic (e.g. Blumenschine, 1995). This analytical trade off has been discussed in a sense by models that recognize upper, intermediate and lower long bone categories (Dominguez-Rodrigo, 1997, Capaldo, 1998), and is related to the debate over the utility of skeletal part profiles versus the analysis of assemblage scale data (Cruz-Uribe, 1988,
Klein et al. 1999). Although error may be introduced, when distinct butchery traces like defleshing or disarticulation are described on specimens identified to element and portion they allow a more detailed assessment of whether these specimens were cut marked earlier or later in the consumption sequence.

Likewise, a finer distinction between ungulate taxa consumed in these experimental models might prove useful for interpreting ancient butchery. Some models differentiate between large and small animal size classes (Dominguez-Rodrigo, 1997 Capaldo, 1998, Selvaggio, 1998). This precision should be extended to all models however, because major animal size class categories (Bunn, 1982) imply completely different amounts of resources available to the primary consumer, secondary and tertiary scavengers, and are likely to involve different patterns of cut marking, tooth marking and fragmentation. These different ecological contexts are blurred together when experimental models do not distinguish large and small animals. Likewise, analysis of specific taxa may provide important insight. For example, perhaps perissodactyl long bones would not be fragmented for marrow owing to the difficulty of removing it from the cavity, which is filled with cancellous bone. Surely, consumption of Perissodactyl within-bone nutrients is not difficult for bone crunching hyenas, who may also be more likely to completely remove a cut marked bone that is not fragmented versus generate cut marked and tooth marked midshaft specimens when chewing the epiphysis off of a fragmented long bone.

Further, most actualistic sequential models do not utilize replicated stone tools in their defleshing butchery trials. The difference between stone and metal knife butchery is still not completely documented with respect to cut mark abundance and location (see
Greenfield, 2006, Nilssen, 2000), but it seems likely that the longer, more effective cutting edge of a metal knife would allow more control over slice placement producing fewer cut marks, and potentially marking fewer anatomical locations. When the presence of cut marks on whole bone is tallied, this is not an issue, but when fragmentation distributes cut marks across long bone fragments, cut mark frequency may be underrepresented on an assemblage scale. Regardless, using replicated stone tools in an experimental context maximizes realism and comparability with the archaeological cases being investigated.

Fragmentation is carried out by bone crunching carnivores or with hammerstones and is therefore a realistic proxy of the ancient effector. However, understanding how the process of fragmentation affects traces of different taphonomic actors is one of the major goals of these models, and I argue that this process is not completely understood because quantifying bone modification on an assemblage scale masks variability that can distinguish different ecological modes of hominin carcass consumption (see Pickering et al., 2006). Sequential actualistic models demonstrate that bone modification introduced on midshaft portions during primary consumption will survive fragmentation and ravaging by scavengers. Implicit in this finding is the fact that cut marks located on epiphyseal portions, which primarily represent disarticulation, will be deleted by bone consumers. If secondary hominin access includes disarticulation prior to hammerstone fragmentation and tertiary hyena scavenging, the general expectation of bone modification would include primary carnivore consumer tooth marks on midshafts (MSHs) and hominin cut marks on epiphyses (EPIs). Hominin fragmentation would introduce percussion marks on MSHs and turn limb bones into a collection of fragments.
Hyena scavenging would also likely introduce tooth marks onto near-epiphysis (NEF) or MSH portions, create smaller shaft fragments, and delete long bone ends (NEFs and EPIs). Therefore we see that interpretations of bone modification are biased toward actions that mark MSHs, since these survive with greater frequency, and that equifinality still plagues the interpretation of the agent of fragmentation since tooth marks can be introduced on MSHs by primary carnivore defleshing or tertiary hyena cancellous bone consumption.

Likewise, it is difficult to interpret the traces of carcass consumption once fragmentation creates additional bone specimens and introduces unidentifiablity. Both carnivore chewing and hammerstone fragmentation create green fractured specimens and as suggested by actualistic models, only leave bone surface traces of their occurrence on a proportion of the fragmented assemblage. For example, in Capaldo’s (1998) hammerstone to carnivore model a maximum proportion of 51% of long bone epiphyses retained tooth marks, and at most 34% had some evidence of hominin processing, and 22% contained marks made by both hominins and carnivores. For near epiphysial and midshaft fragments in this model, the proportion of modified specimens was even lower. Therefore it becomes difficult when examining a green fractured specimen to determine whether its does not bear tooth marks because it was not consumed by carnivores or because tooth marks were simply not incised onto that specimen. For this reason, when bone fragments are involved in calculations that describe the proportions of modified specimens in an assemblage, and this statistic is the foundation for interpreting a paleoecological foraging strategy, it begs the question of accuracy.
Regardless, the sequential actualistic models rarely report raw data that can be examined to determine how bone modifications are distributed across different skeletal elements, and most importantly, which elements and portions preserve bone surface traces in different trials. Without this information it is difficult to reconstruct the likelihood that different stages of consumption will be recorded on distinct parts of the skeleton. Rather we are left to interpret only the overall percentage of bone fragments in an assemblage that bears a type of bone surface modification. And simply because we document the proportion of bone fragments with a type of surface modification that is generated in an experimental context with a known sequence of taphonomic agents, we should not assume that when this same proportion of bone fragments is discovered archaeologically, that it necessarily represents the same ecological context. This method of inquiry implicitly reduces the ancient ecological contexts within which specimens were butchered and the assemblage was formed into a uniform context that allows only hominin-first or carnivore-first interpretations of the whole assemblage. For other ecological interpretations to be possible, higher-resolution models of ancient ecology must be defined and tested with archaeological data.

In summary, sequential actualistic models are an important effort to define testable hypotheses regarding the paleoecology of hominin carcass consumption, but the resolution of their butchery interpretations and their paleoecological implications can be improved based on the actualistic results presented in this dissertation, and when bone modification analysis is not restricted to the assemblage scale but also examines individual archaeological specimens.
Designing taphonomically and ecologically realistic models of carcass consumption

As the sequential actualistic models show, carcass consumption involves a complicated series of taphonomic events whose operation and consequences depend on prior stages of consumption. A number of ecological factors would impact hominins’ carnivorous foraging decisions about which parts to consume or ignore and whether these resources should be consumed on-site or transported. These include the initial state of the carcass. When a carcass is acquired first by hominins through either hunting, or luckily finding a recent natural death, it is complete. When hominins scavenge, either passively when an abandoned carcasses is encountered or when hominins are able to commandeer a carcass form its previous owner, its completeness will be affected by several conditions. Primary predator taxon and group size influence completeness of the encountered carcass when considered in conjunction with the size of the prey animal (Blumenschine, 1986). As multiple naturalistic observations show, the location on the landscape influences carnivores’ competition and therefore the resources remaining for hominin scavenging. In more closed or wooded habitats carcasses are more likely to be encountered with greater amounts of flesh since competition among primary predators is lower, and defleshed marrow-bearing carcasses persist longer since bone consumers may not be as active in these habitats (Blumenschine, 1989, Blumenschine et al., 1994, Dominguez-Rodrigo, 2001).

Hominins’ butchery decisions are made in response to the initial state of the carcass, but are also influenced by other paleoecological factors, and these decisions determine whether an animal is butchered in situ or transported to another location for
consumption. Contemporary ethnoarchaeological observations suggest that the availability of the appropriate butchery tools, the safety of the kill location, the number of foraging individuals and individuals demanding provisioning back at camp are likely factors that mediate field processing and transport decisions (Binford, 1978, Lupo, 2001, Lupo and O’Connell, 2002, O’Connell et al., 1988, 1990, 1992). Although in a Pleistocene context, where hominin social organization is unknown, and whether provisioning of carcass resources existed cannot be determined, we can make the assumption that hominins took full advantage of carcass resources that they encountered, consuming all edible tissues. However, access to stone tools or raw material for their manufacture would affect whether meat was defleshed and bones were broken for their internal nutrients at the kill site or whether these actions took place after transport.

Throughout this discussion of carcass acquisition it is crucial to understand that in some cases hominins may acquire complete carcass parts from scavenged kills. This means that there is equifinality between the order of hominin access and the ecological strategy employed to access a carcass. Specifically, early access does not necessarily equate with hunting or confrontational scavenging and late access does not necessarily equate with passive scavenging.

A new method: hypothesizing early or late carcass access as a sequence of butchery actions

Figure 4-2 depicts a schematic diagram of hominins’ butchery decisions when processing a carcass. As discussed above, the ecological context determines the
nutritional resources available when hominins encounter a carcass, and then decide how
to consume the individual animal. Carcasses are the discrete unit about which butchery
decisions are made, and while butchery creates evidence of its occurrence in the form of
bone surface modifications, it also masks these traces in two important ways. First,
transport of carcass portions will preserve the remains of an individual in different places
on the ancient landscape. Second, fragmentation will turn a butchered animal into a
collection of broken bones, disassociating some unmarked fragments from the traces of
butchery that could be used to interpret their behavioral context, and rendering some
fragments unidentifiable to skeletal element. So in a sense a butchered animal should be
considered as a collection of discrete fragments, and since butchery evidence is not
uniformly distributed across a fragmented skeleton, it is important to describe likely
butchery traces for different parts of the body, and interpret their occurrence on
individual animals represented in archaeological assemblages. Likewise, since identifying
individual animals in a fragmentary assemblage is subject to uncertainty, I argue that a
clearer signal of hominin carcass processing can be inferred when butchery traces are
interpreted on distinct skeletal regions.

Similarly, animals of different size classes are treated separately in this model
since they offer different nutritional value to consumers at each stage of consumption and
their bones have different mechanical properties, which are likely to be differentially
affected by taphonomic processes.

Before describing specific archaeological predictions for early and late access
butchery scenarios, some limitations of this model should be explicitly mentioned. It is
important to remember that archaeological reconstructions cannot always reach higher
levels of inference when equifinality is present. In the case of hominin butchery, it is not possible to distinguish butchery of a fully fleshed limb that was scavenged from a carnivore kill, versus one that was encountered initially by hominins. However, some logical deduction based on predator and prey body size can improve our interpretation of the ecological context that surrounded hominins’ consumption of a particular carcass. For small animals (Bunn’s size class 1 or 2) killed by carnivores defleshing is likely to be relatively complete before a carcass is abandoned (Blumenschine, 1986, Pobiner, 2007). This suggests that hominins butchered flesh from small carcasses that they acquired through hunting, opportunistic confrontational scavenging or taking advantage of known scavenging opportunities like leopard trees and seasonal deaths like mired animals in drying water holes. Larger animals (size 3 and greater) would be difficult for hominins to hunt, but we have no evidence of weapons such as spears during the Pleistocene. Surely hominins could throw rocks, and perhaps stone tools were used to construct wooden spears (Domínguez-Rodrigo, et al., 2001), but the large size difference between hominin predator and ungulate prey makes hunting without the cooperation of many individuals unlikely. Likewise, hunting a very large animal with a few individuals involves extreme risk, especially in light of small fraction of the prey carcass that an individual would consume. So without group provisioning or a behavioral adaptation that included big game hunting, (a fact not supported in the zooarchaeological record until much later in time) it seems unlikely that hominins regularly hunted large prey. Again, we are left with the more parsimonious hypotheses that hominins acquired carcass resources from large animals through confrontational scavenging, or through luckily finding natural deaths or abandoned carnivore kills that retained consumable resources.

**Early access model of hominin butchery**

**Skinning**

Figure 4-3 lists the sequence of butchery actions likely to occur when hominins had first access to carcass resources. To gain access to flesh and ultimately to marrow, the skin must be breached. This is most easily accomplished with transverse slices around the lower limb whose location is based on whether metapodial or phalangeal marrow is targeted. A superior incision up the leg can then be exploited to remove the skin. Skin is a tough material to slice through, and often it can be pulled from the superficial muscle with minimal stone tool slicing. Since cut marks occur only where a tool edge contacts bone, skinning only produces marks around portions of the lower limb where the transverse incision is not buffered by significant ligament or tendon. This usually
produces transversely oriented cut marks on the medial and lateral aspects of the distal metapodial near epiphysis or carpal/tarsal bundles. Skinning then proceeds over the thoracic and abdominal regions, as well as the cervical region and the cranium. The cranium is not modeled in this dissertation, which focuses primarily on butchery of the appendicular skeleton, owing to the infrequency of butchered crania in the archaeological assemblages under study. However, other studies suggest that crania are cut marked during skinning due to their lack of substantial musculature (Nilssen, 2000).

As demonstrated in Chapter 2, skinning produces relatively wider and deeper cut marks than defleshing which can also be distinguished based on their skeletal location.

**Defleshing**

After the skin is removed, defleshing removes muscle masses and is a prerequisite for limb bone fragmentation. In my experience, defleshing with stone tools is most easily accomplished by severing complete muscle bundles near their attachments. This process creates cut marks based on the nature of a muscle attachment. Often relatively large muscle masses can be removed without making many cut marks when they end in tendonous attachments. When muscles attach broadly to the bone surface, filleting produces more cut marks. In general cut marks are common on where limb girdle muscles originate like the basins of the scapula and the innominate excluding the acetabulum. On limb bones, midshafts and near-epiphyses are commonly cut marked during defleshing, but epiphyseal portions are rarely marked, and when they are, the articular bone is almost never incised. This is because resilient tissues like the joint
capsule and connective ligaments typically protect the bone surface. Prior to metapodial fragmentation the anterior and posterior tendon bundles must be removed, which often involves filleting slices on the diaphyses. These tendons can ultimately be removed from the metapodials while still articulated to the phalanges. When the ribs are defleshed, the marks on the lateral surface reflect butchery of the thoracic muscle sheet, and marks on the medial surface especially of anterior ribs are suggestive of severing the connective tissue that supports the thoracic viscera like the lungs and heart.

Defleshing cut marks are narrower and shallower than skinning or disarticulation marks in general, and can be distinguished by skeletal location. Cut mark cluster attributes depend more on different bone portions than they do on experimental factors like the amount of flesh removed or the type of tool used during butchery.

*Disarticulation*

Disarticulation stone tool slices are not necessarily a prerequisite for fragmentation except when separating the hip joint. Likewise fragmentation of the braincase is most easily accomplished inferiorly, necessitating disarticulation of the cranium from the first few cervical vertebrae, although this is not modeled experimentally in this study. On the limb elements, disarticulation primarily marks epiphyseal portions and is more common on articular bone. Cut mark width and depth are typically greater in disarticulation than in defleshing marks. Disarticulation cut mark clusters typically have few marks per cluster and their orientation is usually nearly
parallel compared to defleshing clusters. If sharing of carcass resources occurs prior to fragmentation, disarticulation may be necessary to split the carcass into pieces.

*Hammerstone fragmentation*

Hominins may not always fragment carcasses for within-bone nutrients, especially if a gourmet strategy is practiced because an animal is large relative to the number of consumers, an abundance of carcasses exists, or due to a lack of suitable lithic materials to serve as the hammer.

Hammerstone breakage transforms complete elements into collections of fragments, typically imparting green fracture edges to each specimen. Percussion notches and percussion marks and striae may occur at the point of percussion, and as well, anvil striae may occur where the bone rested on a stone anvil. The exact likelihood that every fragment is percussion marked seems low, but this is not documented experimentally, and is not usually specified for different elements, and is only occasionally described for different long bone portions. In Capaldo’s (1998) hammerstone to carnivore experimental model, of the epiphysis, near-epiphysial and midshaft fragments that survived hyena ravaging only 34%, 28% and 24% respectively had percussion marks.

When fragmentation breaks apart bone shafts it may make some shaft specimens unidentifiable to element, and in an archaeological context, it disassociates these different fragments, making their analytical assignment to the same individual a matter of inference and probability. When this happens, butchery traces introduced during different stages on an individual animal may lose their connection, meaning that evidence of
disarticulation on limb bone ends may become disassociated from cut mark traces of
defleshing on bone shafts.

**Carnivore scavenging**

Scavenging carnivores target the cancellous bone and grease located in long bone
ends as well as bone marrow, and their effects on a carcass depend on whether bones
were previously fragmented by hominins. When whole bones are discarded they may be
removed from the site entirely or chewed in situ, introducing additional tooth marks and
further fragmentation (Marean and Spencer, 1991, Marean *et al.* 1992, Kruuk, 1972,
Capaldo, 1995). When a fragmentary assemblage is scavenged by carnivores, all
epiphyses are typically consumed on site, and in the process green-fractured near-
epiphyseal or midshaft portions with tooth marks and/or tooth notches are generated.
However, when scavenging a hammerstone broken assemblage, Capaldo also reports that
not all specimens are tooth marked. Around half of epiphyses are tooth marked, but only
a third of near epiphyses and a seventh of midshafts bear evidence of carnivore chewing
(Capaldo, 1998). Further, specimens bearing both traces hominin percussion and
carnivore ravaging had a very low incidence in Capaldo’s experimental sample. Around
22% of epiphyses, 8% of near-epiphyses and 3% of midshafts specimens had percussion
marks created by both agents. This is another process in the sequence of consumption
that leaves incomplete evidence of its presence across all bone fragments and removes
evidence of disarticulation on epiphyseal portions.
Late access model of hominin butchery

Carnivore defleshing

Figure 4-4 lists the sequence of butchery actions likely to occur when carnivores have earliest access to a carcass. As multiple experimental and naturalistic observations indicate, the amount of flesh left on a carcass for secondary consumers varies with respect to the number of predators, and their size relative to prey body size. (Blumenschine, 1986, Dominguez-Rodrigo, 1999, Pobiner, 2007, Selvaggio, 1994). The studies suggest in general that during flesh consumption carnivores create tooth marks on long bones shafts and ends, and may create gross gnawing damage on epiphyseal portions. Even during relatively complete consumption flesh scraps are possible around joints, and may be relative common on the distal limb, whereas defleshing almost always removes midshaft muscle (Selvaggio, 1994). Dominguez-Rodrigo (1999) reports relatively common muscle scraps on the distal radioulnae and tibiae, and relatively intact metapodials that are often covered by skin. However, carnivore tooth marks are not introduced onto all elements during defleshing. In Selvaggio’s (1994) whole bone sample where carnivores had first access to flesh only 50% of elements were tooth marked.

Skinning

Skinning is necessary to expose the metapodials. Depending on the extent of limb defleshing by carnivores, skin may cover the carpal/tarsal regions. Skin will be severed
with a superior-inferior incision along the leg and either pulled distally over the hoof or removed with a transverse incision around the distal near-epiphysis of the metapodials or proximal or intermediate phalangeal shafts. Relatively deep cut marks are likely on the medial and lateral aspects of these regions as opposed to the anterior and posterior aspects where substantial flexor and extensor tendons lie. Skinning cut marks are also predicted to occur on the cranium, but these are not modeled explicitly in this study.

Defleshing

Defleshing by hominins depends on the presence of soft tissue left by earlier carnivore consumers. In order to prepare for fragmentation of the metapodials, their anterior and posterior tendon bundles must be filleted, which is likely to create relatively shallow cut marks on the shafts of these bones. Flesh scraps around the distal radioulnae or tibiae may introduce cut marks onto midshafts but are likely to mark the distal near-epiphyses.

Disarticulation

Disarticulation is necessary to separate skeletal elements, but is not a prerequisite for fragmentation except in the case of the hip joint and the cervical/occipital articulation. Deep cut marks on epiphyseal portions and articular bone that have relatively few marks per cluster and a typically parallel orientation characterize defleshing marks.
Hammerstone fragmentation

In a context of secondary hominin access, fragmentation for within-bone nutrients is the targeted resource and is always predicted to occur. As described above, fragmentation creates green fracture-edged specimens and introduces percussion marks and notches onto some proportion of specimens. Long bones bearing carnivore tooth marks from defleshing may therefore be created that do not retain any evidence of hominin fragmentation. Likewise, limb bone ends bearing traces of disarticulation may or may not preserve traces of hammerstone fragmentation or carnivore defleshing. Selvaggio’s (1998) actualistic experiments on hominin scavenging documented that after primary carnivore defleshing, hominin muscle scrap defleshing and hammerstone fragmentation, bone surface traces of different these actions are only present on a fraction of the total experimental assemblage of bone fragments. In fact in Selvaggio’s carnivore to hominid model, 19% of fragments bear no surface traces whatsoever, and only 42% of specimens preserve both defleshing tooth marks and some type of butchery mark from either scrap defleshing or fragmentation.

Carnivore scavenging

When scavenging carnivores ravage a discarded assemblage of bone fragments that represent a carnivore-to-hominin sequence of consumption, they tend to delete epiphyseal portions and compact bones. These bone preserve traces of disarticulation and muscle scrap defleshing, and therefore are likely to be removed. Tooth marks and notches
may be created on midshafts and near-epiphyses and smaller, and larger, more complete limb bone fragments may be transformed into smaller, less identifiable green-fractured shaft specimens when ends are consumed in situ by scavengers. Selvaggio’s (1998) findings indicate that after carnivore scavenging ravages individual carcasses, on average 21% of specimens do not retain any surface mark evidence and only 30% of specimens preserve bone surface of evidence of both carnivore tooth marking and hominin butchery. Across different long bone portions categories, the mean percentage of unmarked specimens in the carnivore-hominid-carnivore model is very low in epiphyseal and near-epiphyseal fragments (0% and 4% respectively), and increased in midshaft specimens (30%). Fragments that preserve both carnivore and hominin surface modifications are quite common on epiphyseal specimens (74%), although many epiphyses are actually deleted during carnivore scavenging, but only 36% and 30% respectively of near-epiphyses and midshaft specimens have traces of both actors.

Sequential butchery model implications

The early and late models of hominin butchery action sequences are based on actualistic observations and logical deduction, but the specific occurrence of traces of each agent and action are a matter or probability. Actualistic models currently do not have the resolution to build secure quantitative models that predict the likelihood that specific skeletal portions will preserve traces of their taphonomic history of carcass consumption. With such uncertainty, it remains difficult to interpret zooarchaeological assemblages with inferential models that rely on proportions of specimens with a
particular type of bone surface modification. This difficulty is introduced by the
dissociative properties of fragmentation, which render some specimens unidentifiable and
create others that do not bear traces of the sequence of consumption processes that
affected them. When these fragments are analyzed by the zooarchaeologists they are
considered part of the natural background scatter of bones on the ancient land surface, or
they may be incorrectly assigned to a causal taphonomic agent or process.

Despite this grim picture of unidentifiability that can be argued to impact any
fragmentary bone specimen, careful interpretation of butchery evidence may still be able
to tease apart whether certain specimens in an assemblage represent hominin’s early or
late access to flesh. This discussion centers around the distinction of defleshing and
disarticulation butchery actions on the elbow

Distinguishing defleshing and disarticulation cut marks on the elbow joint

The elbow contains some of the densest bone portions in the mammalian skeleton,
specifically the distal humerus and proximal radio-ulna. These portions are therefore very
resistant to abiotic density-mediated destruction (Lam et al., 1999) and are among the
most common bone portions that survive carnivore ravaging (Binford, 1981, Marean and
Spencer, 1991, Pobiner, 2007). Because of the large muscles that overlie the elbow and
bony anatomy necessary to restrict motion to the para-sagittal plane in ungulates, the
elbow joint is commonly cut marked during both defleshtal and disarticulation. If these
cut marks can be distinguished, it may be possible to determine whether a specimen
represents defleshing (and possible disarticulation) during hominins’ early access, or
disarticulation alone, which represents hominins’ consumption of a scavenged carcass.

The elbow joint is likely to be cut-marked in different ways during defleshing and
disarticulation. Typically cut marks from these butchery actions can be identified based
on skeletal location, with defleshing marks occurring on limb bone shafts and near-
epiphyseal shaft portions and disarticulation marks occurring on epiphyseal bone.
However due to the configuration of the elbow joint in most mammals, both
disarticulation and defleshing are likely to cut mark the distal humeral shaft, the
olecranon process of the ulna and the proximal radius (Binford, 1981, Nilssen, 2000).

The skeletal location of cut marks has been documented by various researchers in
a variety of contexts, but these investigations are characterized by a lack of experimental
control or direct observation over the butchery events that produced these marks.
Biinford’s (1978) observations of Nunamiut discarded bone assemblages suggested that
defleshing and disarticulation may both introduce overlapping cut marks on the elbow.
But in reality these different butchery processes were not observed and the cut marks they
produced were not studied in isolation from one another. Further, while caribou
comprised most of the butchered assemblage, they were often disarticulated with metal
axes while frozen, and at times defleshing proceeded in this fashion as well. Binford’s
goal was to document bone assemblages after they exited the nutritive phase of their
taphonomic history, so as opposed to observing the butchery process, refuse assemblages
were described after the butchered remains of many caribou were thrown into a central
yard and ravaged by dogs living in the village.
Nilssen (2000) distinguishes defleshing cut marks from disarticulation in an experimental context, which offers control over different butchery actions’ mark location, but his conclusions are limited by the lack of a realistic experimental scenario. Nilssen was able to conduct some butchery experiments with replicated stone tools, but most trials utilized metal knives for butchery. Also, carcass processing decisions were constrained by the fact that he utilized carcasses shot by contemporary hunters who were interested in retaining the hide and filleting large muscle strips for the production of biltong. In his experimental scenario, disarticulation of each skeletal element proceeded while complete limb flesh surrounded each joint. Although an experienced butcher processes the carcasses, it is likely that when attempting to sever limb elements while the soft tissue that bind these joints are hidden by overlying flesh, disarticulation cut marks might be imparted on a greater variety of skeletal locations.

To improve on the security of these previous observations, my dissertation exerted experimental control over the mark location of defleshing and disarticulation butchery by isolating these actions in different trials, and conducted all butchery with replicated stone tools. My findings corroborate these observations that both butchery actions are likely to mark various portions of the elbow joint.

Distinguishing the distinct butchery signatures of defleshing and disarticulation with careful experimental documentation is important since cut marks on meaty bone portions (like the humeral DNEF and olecranon process) are typically attributed to defleshing, which is usually linked with primary hominin access to carcasses but may in fact represent disarticulation of the elements of a defleshed carcass during hominin scavenging.
Elbow musculo-skeletal anatomy

The musculo-skeletal anatomy of the domestic cow (Constantinescu and Constantinescu, 2004) is described to illustrate the tissues severed during defleshing and disarticulating the elbow and identify which skeletal landmarks are likely to preserve cut mark traces of these slices. Specifically, the anatomical landmarks are described in relation to the zooarchaeological long bone portion categories employed by Blumenschine (1995 for example) since these categories form the analytical basis for most interpretations of ancient butchery and carnivore consumption of carcass resources. See Appendix A for images of this musculo skeletal anatomy.

The skeletal component of the ungulate elbow joint consists of the distal humerus, which articulates in a hinge-like joint with the fused radioulna. The distal epiphyseal (DEPI) portion of the humerus consists of the trochlea and capitulum, which is oriented anterior and inferior of the medial and lateral epicondyles, which have non-articular bony areas on the posterior and medial and lateral faces on the DPEI. The superior border of the DEPI is defined in this study by a transverse plane located at the most superior point of the humeral condyle that is oriented perpendicular to the diaphyseal axis. The distal near-epiphysis (DNEF) portion of the humerus includes the cortical area of the epicondyles superior to their DEPI portions and is bounded by the superiorly when the lateral supercondylar crest joins the midshaft.

The radioulna is treated as two separate skeletal elements for this analysis since these parts are often found in isolation in archaeological context. The fovea capitis of the
radial proximal epiphysis (PEPI) is oriented superiorly and articulates with the humeral DEPI. Its has a small area of non-epiphyseal bone inferior to the articular portion on all sides that is bounded inferiorly by the metaphyseal line. The proximal near-epiphysis (PNEF) begins distal of the metaphyseal line, includes the laterally-oriented radial tuberosity, and terminates at the inflection point on the radial shaft when the medial and lateral edges take on a more angle.

The proximal ulna is more difficult to classify into the cylindrical long bone portion scale, so its anatomical regions are used instead. This analysis defines the olecranon process and proximal shaft as the anatomical regions of interest. The ulna is fused posteriorly to the radius in ungulates and together they make up the semi-circular hinge joint that surrounds the distal humeral epiphysis. The lateral coranoid process of the ulna fits into a notch in the posterior portion of the fovea capitis and the trochlear notch curves superiorly and anteriorly over the fovea capitis. Unlike other mammals, in ungulates this joint is constrained skeletally to allow only flexion and extension of the elbow. When fully extended, the olecranon process of the ulna locks into the olecranon fossa of the distal humerus, further restricting motion to the sagittal plane. The superior olecranon tuber is a site for large muscle attachment and is connected to the olecranon process proper at a metaphysis. Inferior to the trochlear notch, the proximal ulnar shaft fuses to the posterior radius on its PEPI and PNEF portions. The proximal antebrachial space occurs inferior to the proximal fusion site is the, and terminates on the midshaft region of the ulnar spine when it again fuses to the radius. Therefore in this analysis the proximal ulnar shaft is an analogous region to the radial PEPI and PNEF.
Defleshing a complete elbow joint requires slices over all elbow bone portions, but cut mark locations are likely to be constrained by the specific muscle tissues targeted for defleshing as well as the nature of their skeletal origin or insertion and the presence of the joint capsule and ligaments holding the elbow in articulation. The *triceps brachii* is a large elbow extensor that covers the medial, lateral and posterior faces of the humeral DNEF and inserts into the medial, lateral and posterior/superior aspects of the olecranon process. The *tensor fasciae antebrachii* lies superficial to the medial head of the triceps brachii and inserts into the posterior/superior olecranon process. Elbow flexors include the *brachialis* muscle, which originates on the posterior-lateral humeral shaft and articulates on the anterior-medial radial shaft, and the *biceps brachii* muscle, which runs along the anterior-medial humeral shaft and articulates to the radial tuberosity on the anterior-medial aspect of the radial PNEF. The *coracobrachialis* muscle attaches on the medial humeral DNEF and on the anterior radial PNEF. The *flexor carpi radialis* originates on the distal medial humerus and runs down the medial face of the radius. The *flexor carpi ulnaris* attaches on the olecranon process and runs medially down the ulnar shaft. Moving anteriorly to posteriorly, the *extensor carpi radialis* runs anterior-laterally across the elbow, the *common digital extensor* runs laterally over the elbow, the *lateral digital extensor* originates on the lateral process of the radial PNEF and the proximal ulna, the *extensor carpi ulnaris* originates on the lateral non-articular portion of the humeral DEPI and runs over the lateral face of the olecranon near the semi-lunar notch, and the three heads of the *deep digital flexor* originate on the humerus, radius and ulna and run posteriorly down the lateral side of the ulna.
In sum, the elbow joint is overlain primarily by flexor and extensor muscle bundles. The most efficient cuts involve transverse slices near these functional units skeletal attachment sites or tendinous origins to remove large muscle bundles. This involves transverse slices across the superior aspect of olecranon process and between its anterior border and the humeral epicondyles while the elbow is in flexion to sever the triceps attachment. The humeral elbow extensors are then filleted up the posterior humeral shaft. The elbow flexors of the humerus are typically severed proximally near the PEPI and with transverse slices across the proximal radius. The radius is typically defleshed by a transverse slice around its DNEF portion, which severs the tendons that move the carpals and digits. These anterior (radial) and posterior (ulnar) muscle groups are encased in fasica and are easily removed in discrete bundles with minimal slicing until their proximal skeletal origins are encountered. Transverse slices the around the proximal anterior, medial and lateral radius and the proximal aspect of its shaft, and the medial, posterior and lateral olecranon and proximal ulnar shaft and non-articular humeral DEPI sever these muscle attachments.

Deep connective tissues hold the elbow in articulation, but in reality, this joint is easily disarticulated when the musculature of the forelimb has been defleshed. Particularly, when the *triceps brachii* muscle, which attaches on the olecranon process and along the posterior humerus and holds it in articulation with the radioulna is severed, the joint loses significant strength. The joint capsule is a mass of fibrous tissue that covers the articular surfaces on the distal humerus and proximal radius. The medial collateral ligament runs between the medial non-articular portion of the distal humeral epiphysis to the proximal radius, and splays widely, attaching on the rugose non-articular
surface of the radial PEPI and the PNEF along its entire medial face and the medial side of the olecranon posterior to the semilunar notch. It is overlain by the small *pronator teres* muscle, whose function is greatly reduced in ungulates since they do not supinate their forelimbs. The lateral collateral ligament similarly originates on the lateral non-articular surface of humeral DEPI and splays widely to attach on the lateral process on the radial PNEF, the non articular portion of the radial PEPI and the olecranon process posterior to the semilunar notch. Connective tissue does not cover the posterior-inferior aspect of the distal humeral epicondyles or the anterior aspect of the olecranon process.

The most efficient method to disarticulate a defleshed elbow joint uses a transverse slice to sever the joint capsule across its anterior aspect aiming directly for the articulation of the humeral DEPI and radial PEPI. Then the slice can be followed medially or laterally, cutting through the collateral ligaments. Hyper-flexion of the elbow can help put tension on the ligaments making them easier to sever. Once the anterior aspect of the joint capsule and either the medial or lateral connective tissue is severed, the joint can be bent to expose the proximal and distal epiphyseal surfaces, and a tool edge can be slipped between the bones, or the slice can be followed around in a transverse direction. Regardless of the particular orientation of the limb bones during disarticulation, the slices employed are likely to impart transverse slices on the anterior aspect of the joint and the medial and lateral faces of the humeral non-articular DEPI. But depending on the particular degree of elbow flexion when the medial and lateral collateral ligaments are severed, these slices may extend superiorly or posteriorly onto the olecranon process. This may cause a variable orientation of disarticulation slices on the olecranon, which may run in a transverse direction if the elements are severed while in anatomical position,
or these marks may assume a superior-inferior orientation if the ligaments are severed while the elbow is fully flexed.

**Cut mark traces of disarticulation versus defleshing on the elbow**

Table 4-1 shows the proportion of butchery trials where defleshing and disarticulation cut marks occurred. In total, four bulk and four scrap defleshing trials comprised the eight defleshing trials examined, and these were compared to four disarticulation trials. Half of the trials were conducted with unmodified stone flakes and half were conducted with bifacial core tools (see Table 2-1 and experimental butchery methodology in Chapter 2). In general, both butchery actions had the potential to mark every skeletal portion, but it was observed that the non-articular portion of the humeral DEPI was rarely cut-marked. In fact only one defleshing trial created marks at this location. In both cows and goats, defleshing trials more frequently produced cut marks on the humeral DENF and radial PNEF, and disarticulation more frequently marked the humeral DEPI, the proximal non-articular portion of the radial PEPI, and the proximal ulnar spine. The olecranon process was cut marked more frequently by defleshing in cow trial, but more commonly marked by disarticulation actions in the goat sample. In all cow trials defleshing never cut-marked the humeral DEPI and disarticulation never marked the humeral non-articular portion of the DEPI or the radial PNEF. In all goat trials the humeral non-articular portion of the DEPI was not cut-marked by either action and disarticulation never cut-marked the proximal ulnar spine.
As demonstrated in an earlier chapter disarticulation creates cut marks that are wider and deeper in cross section than defleshing marks across the entire appendicular skeleton, which is both a function of less dense epiphyseal portions targeted during disarticulation and the increased force and perpendicular cutting angle of slices uses to sever ligaments. Cut mark width and depth are compared on elbow bone portions to determine whether these measurements can help distinguish defleshing and disarticulations when their cut marks co-occur on the skeleton. In cow trials the olecranon process contains disarticulation cut marks that have a significantly greater median width and depth than defleshing cut marks (Figures 4-5 and 4-6). In contrast, the median depth of defleshing cut marks was significantly greater compared to disarticulation mark depth on the humeral DNEF and ulnar spine, although these sample had identical interquartile ranges and were influenced by a small number of cut marks. Similarly, in goat trials disarticulation created a significantly wider and deeper median cut mark than defleshing on the olecranon process (Figures 4-7 and 4-8). Disarticulation of the goat elbow also produced significantly wider marks on the humeral DNEF and DEPI although their median depths are indistinguishable these relationships are influenced by single marks. On the proximal radius in goat trials, median cut mark depth is significantly greater for disarticulation in the PNEF whereas the single defleshing cut mark on the non-articular portion of the PEPI is significantly deeper than the median disarticulation mark on this portion. In summary, the olecranon process in both goats and cows contains a sample of deeper and wider disarticulation cut marks that can be distinguished from defleshing cut marks.
Cluster attributes change more with musculo-skeletal anatomy at a particular bone portion and cluster area than tool type or the amount of flesh removed during defleshing. Here, disarticulation clusters are compared to defleshing cut mark clusters on same bone portion and again on the same anatomical location to help identify the cut mark signatures of these distinct butchery actions. Boxplots are used as visual representations of the Kruskal-Wallis test for significantly different sample medians at $p = 0.05$. When notches representing the 95% confidence intervals do not overlap, the sample medians are considered significantly different suggesting that these samples of values belong to different populations. Cut mark count and median length are calculated for all clusters, but cluster area, standard deviation of cut mark length and angle are not calculated for singleton clusters.

Sample median differences represent the fact that these butchery actions create clusters with different attributes, but diagnosing the butchery action that created an archaeological cut mark cluster, requires non-overlapping sample values, or for an archaeological cluster to fall completely outside of the range of observed in this experimental sample.

**Humeral DNEF**

When the entire humeral DNEF is considered in cow trials, defleshing clusters contain more cut marks than disarticulation clusters, have a greater median cut mark length, and greater standard deviation of cut mark length (Figures 4-9, 4-10, 4-11, 4-12, 4-13).
Examining cow cut mark clusters across different skeletal locations shows that only defleshing cut-marked the posterior aspect of the humeral DNEF, and only one disarticulation cluster occurs on the anterior portion, and its cut mark count and length overlaps with the median value for defleshing (Figures 4-14, 4-15, 4-16, 4-17, 4-18). Cluster area and standard deviation of cut mark length is greater for the defleshing cluster on the anterior DNEF, but standard deviation of cut mark angle is greater for the disarticulation cluster. On the medial face of the DNEF, defleshing clusters have significantly more marks, a significantly greater area, a significantly longer median cut mark and significantly higher standard deviation of cut mark length and angle than disarticulation clusters. The same relationships are present on the lateral face of the DNEF, but the differences between median values is only significantly greater for defleshing in cluster area, standard deviation of cut mark length and cut mark angle per cluster.

In goats, the humeral DENF has multiple defleshing clusters that contain significantly more cut marks than the single disarticulation cluster which only contains one cut mark (Figures 4-19). The length of the disarticulation cut mark overlaps with the median value of the defleshing marks (Figure 4-20). This singleton cluster influences most comparisons on this portion (Figures 4-21, 4-22, 4-23).

When different anatomical locations on the humeral DNEF are examined, defleshing cut marks the anterior, posterior, medial and lateral faces, but disarticulation marks only the lateral face. On the lateral face, the single defleshing cluster contains a single mark which is significantly less than the number of cut marks in defleshing
clusters, but equivalent in length to the defleshing clusters on the lateral face (Figures 4-24, 4-26).

**Humeral DEPI**

In cows, the DEPI of the humerus contains disarticulation cut marks which occur on epiphyseal bone and defleshing cut marks which occur on non-epiphyseal areas of the DEPI. The defleshing clusters have significantly more marks, a significantly greater cluster area, and significantly greater standard deviations of cut mark length and angle (Figures 4-9, 4-10, 4-11, 4-12, 4-13).

The single defleshing cut mark cluster occurs on the medial face of the non-epiphyseal portion of the DEPI, specifically the area superior to the trochlea and below the metaphyseal fusion of the inferior medial epicondyle, and disarticulation clusters occur only on anterior and lateral portions of the DEPI proper. The defleshing cluster contains four cut marks, a significantly greater cut mark count than the disarticulation clusters that occur on the anterior and lateral faces (Figure 4-14). The median length of the defleshing cluster on the medial face is significantly greater than the disarticulation cluster on the lateral face, but overlaps in length with the anterior disarticulation clusters’ median length (Figure 4-16). The defleshing cluster also has a greater area and standard deviation of cut mark length and angle compared to the disarticulation cut marks, but these comparisons all involve individual clusters (Figures 4-15, 4-17, 4-18).

In goat trials, a single defleshing and three disarticulation clusters occur on the epiphyseal bone of the humeral DPEI. Disarticulation clusters have a small number of
marks, but significantly more than the defleshing cluster, which is a singleton, and the median lengths of the disarticulation and defleshing samples are equivalent (Figures 4-19, 4-21). Since the one defleshing cluster is a singleton, standard deviation of length, angle and cluster area cannot be compared with multiple-mark disarticulation clusters (Figures 4-20, 4-22, 4-23. Disarticulation and defleshing clusters co-occur on the lateral face of the DEPI, but both involve comparing a single cluster. The disarticulation cluster on the lateral face contains two cut marks, and has a slightly longer median cut mark length (Figure 4-24, 4-26).

Radial PEPI

All clusters in cow trials occur on the non-epiphyseal bone of the radial PEPI, superior to the metaphyseal line, but not on the lip of the epiphysis itself. On the entire bone portion, disarticulation clusters contain significantly more cut marks, a significantly greater area, and significantly greater standard deviation of cut mark length and angle, although medial cut mark length is similar for both butchery actions (Figures 4-9, 4-10, 4-11, 4-12, 4-13).

Clusters of defleshing marks occur on the medial and anterior faces of the radial PEPI, but disarticulation only cut marks the anterior face (Figures 4-14, 4-15, 4-16, 4-17, 4-18). On the anterior face, disarticulation clusters contain significantly more cut marks, a significantly greater cluster area and standard deviation of cut mark length and area than defleshing clusters, but equivalent median cut mark lengths.
Goat trials contained one defleshing cluster that is a singleton, and two
disarticulation clusters on the non-epiphyseal sections of the radial PEPI (Figures 4-19, 4-20, 4-21, 4-22, 4-23). The disarticulation clusters contained significantly more cut marks, but are significantly shorter. Because of the singleton cut mark in the defleshing sample, cluster area, standard deviation of cut mark length and angle are not compared. Similarly, the defleshing cut mark occurs on the lateral face of the PEPI whereas the disarticulation clusters occur on the anterior face. (Figures 4-24, 4-25, 4-26, 4-27, 4-28).

Radial PNEF

In cow trials, only defleshing created cut marks on the radial PNEF (Figures 4-9, 4-10, 4-11, 4-12, 4-13). Compared to the PEPI, PNEF clusters contained many more cut marks, but were similar in length. Most comparisons between anatomical locations include a single cluster, but the posterior face of the PNEF has the greatest number of cut marks, cluster area and standard deviation of cut mark length, the longest marks tend to occur on the anterior and posterior faces, and the greatest standard deviation of cut mark angle occur on the lateral face (Figures 4-14, 4-15, 4-16, 4-17, 4-18).

In goat trials, both defleshing and disarticulation created cut mark clusters on the radial PNEF (Figures 4-19, 4-20, 4-21, 4-22, 4-23). On the entire bone portion, both actions introduced clusters with similar numbers of cut marks and median mark lengths, although defleshing created clusters of slightly, but significantly greater area, standard deviation of cut mark length and area.
Defleshing created clusters of marks on each face of the radial PNEF, but disarticulation only marked the anterior face in goat trials (Figures 4-24, 4-25, 4-26, 4-27, 4-28). Similar to the relationships described above, on the anterior face, disarticulation and defleshing clusters had similar numbers of cut marks, but defleshing created a significantly longer median cut mark and clusters with a significantly greater area and standard deviation of cut mark length and angle.

**Ulnar olecranon process**

In cows, cut mark clusters made by defleshing and disarticulation are similar in most attributes (Figures 4-9, 4-10, 4-11, 4-12, 4-13). Cut mark count, cluster area, median cut mark length, and standard deviation of cut mark length and angle are all indistinguishable between butchery actions, but in all comparisons defleshing clusters have the greatest observed values.

Examining different faces of the olecranon process highlights some differences between defleshing and disarticulation, which are constrained by the wide medial and lateral faces and narrow anterior and posterior crests (Figures 4-14, 4-15, 4-16, 4-17, 4-18). In the cow sample defleshing cut marked all faces of the olecranon, but disarticulation cut marked only the anterior and posterior crests. Disarticulation created clusters with significantly more cut marks and greater area than defleshing on the anterior crest, but in contrast, clusters with more marks and significantly greater area were created on the posterior crest by defleshing. Median cut mark length and standard deviation of
cut mark length are similar for both actions on the anterior and posterior crests, and equivalent or lower than values on the medial and lateral faces.

In goat trials, most cluster attributes are similar between defleshing and disarticulation on the olecranon process (Figures 4-19, 4-20, 4-21, 4-22, 4-23). Cut mark count per cluster, cluster area, and standard deviation of cut mark length and angle are similar, although defleshing clusters have a significantly longer median cut mark than disarticulation clusters.

On the different anatomical areas of the olecranon, defleshing clusters created clusters of marks with significantly more cut marks on the medial face, and non-significant, but higher numbers of cut marks on the anterior, posterior and lateral faces (Figure 4-24). Defleshing cluster area is significantly greater on the medial face and non-significant but greater on the posterior crest (Figure 4-25). Median cut mark length is similar for disarticulation and defleshing on the medial and posterior olecranon, but significantly longer for disarticulation clusters on the anterior crest and lateral face (Figure 4-26). However, standard deviation of cut mark length per cluster is significantly higher in defleshing clusters on the medial face and significantly lower on the posterior spine (Figure 4-27). Similarly, standard deviation of cut mark angle is significantly lower on defleshing clusters on the posterior spine, but equivalent on the medial face (Figure 4-28).

Ulnar spine
The proximal region of the ulnar spine in cows displays similar cluster attributes for defleshing and disarticulation actions, although the disarticulation sample only contains two clusters. No significant differences occur and this small sample also results in the relatively narrow range of values for the disarticulation clusters compared to the defleshing sample (Figures 4-9, 4-10, 4-11, 4-12, 4-13).

The anterior aspect of the spine is fused to the posterior radius and contains no cut marks. In cows, defleshing cut-marked all sides of the spine but disarticulation cut-marked only the posterior edge. On the posterior spine, disarticulation clusters’ cut mark count and area are similar to the defleshing sample values, but in general defleshing clusters on all anatomical locations have more marks and greater area, but these differences are non-significant (Figures 4-14, 4-15. Disarticulation clusters on the posterior spine have a significantly longer median mark and significantly greater standard deviation of cut mark length than defleshing clusters (Figures 4-16, 4-17). Standard deviation of cut mark angle is similar for the posterior disarticulation samples and all other defleshing samples, but in general, defleshing clusters include a greater range of angle standard deviation (Figure 4-18).

In all goat trials only defleshing cut marked the proximal ulnar spine, and these clusters were restricted to the medial and posterior faces. Cut mark count, cluster area, median cut mark length and standard deviation of cut mark length are significantly greater on the medial spine compared to the posterior portion (Figures 4-24, 4-25, 4-26, 4-27, 4-28).

**Summary of butchery marks on the elbow**
When elbow cut mark cluster attributes are examined, disarticulation and defleshing are best distinguished on the humeral DNEF and the radial non-articular portion of the PEPI, and can be identified by the number of cut marks at different skeletal locations. In cows, examining cut mark count per cluster at different skeletal locations shows that on the humeral DNEF, defleshing created clusters with more marks than disarticulation in general (figure 4-14). Likewise in goats, disarticulation introduced significantly fewer cut marks, and these only occur on the medial and lateral faces of the humeral DNEF (Figure 4-24). The posterior surface of the humeral DNEF was never cut marked during disarticulation. In goat trials, humeral DEPI disarticulation clusters have significantly more cut marks, but this is influenced by the occurrence of one singleton defleshing cluster on the DEPI (Figure 4-19). Median cut mark length per cluster is significantly longer on the humeral DNEF in cow defleshing trials but equivalent for both butchery actions on the radial non-articular PEPI (Figure 4-11). This relationship is reversed in goats, where defleshing created clusters with a significantly greater median cut mark length on the radial non-articular PEPI and equivalent length on the humeral DNEF (Figure 4-21). In cow trials the standard deviation of cut mark length per cluster is significantly greater for defleshing on the humeral DNEF but significantly greater for disarticulation on the radial non-epiphyseal PEPI (Figure 4-12). Standard deviation of cut mark angle shows a similar pattern for the cow radial non-epiphyseal PEPI, but equivalent values for defleshing and disarticulation on the humeral DNEF (Figure 4-13). In goat trials, singleton clusters in the humeral DNEF disarticulation and radial non-articular PEPI defleshing sample do not allow calculation of standard deviation of cut
mark attributes (Figures 4-19, 4-24). Clusters of cut marks made during defleshing and
disarticulation on the olecranon process and the proximal ulnar spine have similar median
values for all cluster attributes examined in cow trials, and in goat trials, disarticulation
did not produce cut marks on the proximal ulnar spine (Figures 4-9 and 4-14, 4-19, 4-24).
It is worth noting that although defleshing and disarticulation cut mark cluster samples do
not have significantly different median values, defleshing the olecranon process of both
goats and cows tended to create clusters with a greater number of marks, greater cluster
area, a longer median mark, and a greater standard deviation of cut mark length.

In summary, when cut mark from different butchery actions co-occur on bone
portions, defleshing the elbow is more likely to create cut mark clusters on the humeral
DNEF, and these clusters tend to contain more marks which are typically longer, and
have a more scattered distribution of cut mark length and angle. In contrast,
disarticulation tends to create more clusters on the radial non-epiphyseal PEPI, which
contain more cut marks that are typically longer and have more scattered distributions of
cut mark length and angle per cluster.

Conclusion: Working with model predictions

In summary, it is possible to distinguish defleshing from disarticulation on
different long bone portions by the skeletal location of cut marks, their cross-sectional
morphology, and some attributes of their cluster geometry. Overall this model may seem
to favor these conclusions and ignore important contextual information from other
taphonomic process like carnivore tooth marking or hammerstone percussion evidence
that can contribute to inferences about whether hominins had early access to carcass resources. But the reliance on cut mark data is suggested as a secure method for interpreting the Koobi Fora zooarchaeological assemblages studied in the next chapter because it takes advantage of their taphonomic characteristics. To use actualistic information to construct a model that defines archaeologically testable hypotheses, the model must pose questions that can be answered by the assemblage in question. As will be demonstrated in the next chapter, the Koobi Fora assemblages are very fragmentary but almost entirely lack carnivore tooth marks, and have a low incidence of hammerstone damage.

I advocate examining the bone modification traces present on each specimen and on archaeologically defined individual animals that are grouped into taxon and body size categories. While, it is impossible to determine the likelihood that each bone fragment truly records the taphonomic traces of every stage of consumption it passed through, determining which bones are suggestive of hominin or carnivore defleshing and marrow access will illustrate in general which body parts were consumed by different taphonomic agents and give a rough idea each one’s contribution to assemblage formation. In this inferential context we are forced to use the bone surface modification data that we can observe archaeologically, and try to refine our inferences in light of analytical uncertainty.

Finally, as discussed in this chapter, since the elbow joint is commonly preserved due to its density, and has the likelihood of retaining evidence of different ecologically constrained strategies of hominin butchery and carnivore consumption, it is useful to
examine the bone surface evidence preserved on different anatomical location on the elbow.
Figure 4-1. Partly consumed female eland carcass.
Figure 4-2. Butchery decision schematic.
### PRIMARY AGENT & ACTION: HOMININ BUTCHERY

<table>
<thead>
<tr>
<th>Action</th>
<th>Mark locations</th>
<th>Butchery function</th>
<th>Diagnostic traces</th>
</tr>
</thead>
</table>
| Skinning                      | Metapodial DNEF or 1st or 2nd Phalanges shaft or     | Necessary to expose limb flesh.                        | Deep cut marks, transverse orientation, most likely on medial and lateral surfaces.
| Defleshing                    | Limb MSH’s and NEF’s, girdles and ribs               | Defleshing function, and necessary to prepare limb bones for fragmentation. | Cut marks common except on EPI’s. Marks are relatively shallow. Cluster attributes like cut mark count and median mark length depend on skeletal location. |
| Elbow: Humeral DNEF, DEPI, Radial PEPI, PNEF, Olecranon process |                                                                 |                                                                                   | Shallow marks are typical. On humeral DNEF long marks occur in large clusters, and have scattered angular orientation. Humeral DEPI marks are rare and typically occur on non-articular bone. Radial PEPI marks are rare and occur on non-articular bone in larger clusters compared to disarticulation. Radial PNEF marks are common, and occur in large clusters with long marks and scattered orientation. Defleshing the olecranon produces large clusters on the medial and lateral faces and small clusters of short marks on the anterior crest. |
| Hip: Innominate, acetabulum, and proximal femur |                                                                 |                                                                                   | Relatively shallow marks all over ilium, ischium and pubis, but not near the acetabulum. Rare marks on greater trochanter and femoral neck that are shallow. |
| Metapodial tendon removal     | Necessary to prepare metapodials for fragmentation.  |                                                                                   | Filleting marks on MP shafts. Tendons can be removed while articulated to phalanges. |
| Medial rib shafts             | Thoracic viscera removal.                            |                                                                                   | Filleting marks on medial rib shafts.                                             |
| Disarticulation               | Limb EPI’s                                           | Not necessarily a prerequisite for fragmentation. | Deep cut marks on EPI’s. Cut mark count per cluster is typically low, and mark orientation is nearly parallel. |
| Elbow: Humeral DNEF, DEPI, Radial PEPI, PNEF, Olecranon process |                                                                 | Necessary to separate elements, but not a prerequisite for fragmentation. | Marks are typically located on articular bone and are deep. Humeral DNEF clusters are usually singletons or have few marks. Radial PEPI marks tend to occur as large clusters on the anterior face. Marks are rare on the PNEF, only occur on the anterior face, and are typically short and occur in small, relatively parallel clusters. Disarticulation creates relatively large clusters of long marks on the anterior crest of the olecranon and clusters with relatively fewer marks on the medial and lateral faces. |
| Hip: Innominate, acetabulum, and proximal femoral | Necessary prerequisite for hindlimb fragmentation.     |                                                                                   | Deep cut marks on femoral head and acetabulum, and occasionally on greater trochanter and lateral non-articular bone around acetabulum. |
| Cranium/cervical vertebrae    | Likely prerequisite for fragmentation of cranium.    |                                                                                   | Cut marks on occipital condyles and/or cervical vertebrae near articular bone and perpendicular to connective tissue orientation. |

### SECONDARY AGENT & ACTION: HOMININ FRAGMENTATION

| Hammerstone Fragmentation   | Fragments limb bones. Creates percussion marks, percussion notches and green fracture edges. Renders some MSH fragments unidentifiable. May disassociate defleshing marks on shafts from disarticulation marks on EPI’s. |

### TERTIARY AGENT & ACTION: CARNIVORE SCAVENGING

| Carnivore Ravaging          | Deletes EPI fragments and compact bones. Creates tooth marks, tooth notches and green fracture on MSH’s. Removes evidence of disarticulation. |

Figure 4-3. Early hominin access consumption sequence.
## PRIMARY AGENT & ACTION: CARNIVORE DEFLESHING

| Carnivore Defleshing | Removes flesh except for metapodial tendons, and possible flesh scraps around joints and on distal radioulnae and tibiae. Creates tooth marks on long bones. |

## SECONDARY AGENT & ACTION: HOMININ BUTCHERY

<table>
<thead>
<tr>
<th>Action</th>
<th>Mark location</th>
<th>Butchery function</th>
<th>Diagnostic traces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skinning</td>
<td>Metapodial DNEF or 1st or 2nd phalanges shaft or Carpals or tarsals sets</td>
<td>Necessary to expose metapodial shafts.</td>
<td>Deep cut marks, transverse orientation, most likely on medial and lateral surfaces.</td>
</tr>
<tr>
<td>Defleshing scraps</td>
<td>Metapodial tendon removal</td>
<td>Necessary to prepare metapodials for fragmentation.</td>
<td>Filleting marks on MP shafts. Tendons can be removed while articulated to phalanges.</td>
</tr>
<tr>
<td></td>
<td>Scraps possible on radioulnae and tibiae.</td>
<td>Defleshing function.</td>
<td>Possible filleting marks on MSH and distal portions.</td>
</tr>
<tr>
<td>Disarticulation</td>
<td>Limb EPI’s</td>
<td>Necessary to separate elements, but not a prerequisite for fragmentation.</td>
<td>Deep cut marks on EPI’s. Cut mark count per cluster is typically low, and mark orientation is nearly parallel.</td>
</tr>
<tr>
<td></td>
<td>Elbow: Humeral DNEF, DEPI; Radial PEPI, PNEF; Olecranon process</td>
<td>Necessary to separate elements, but not a prerequisite for fragmentation.</td>
<td>Marks are typically located on articular bone and are deep. Humeral DNEF clusters are usually singletons or have few marks. Radial PEPI marks tend to occur as large clusters on the anterior face. Marks are rare on the PNEF, only occur on the anterior face, and are typically short and occur in small, relatively parallel clusters. Disarticulation creates relatively large clusters of long marks on the anterior crest of the olecranon and clusters with relatively fewer marks on the medial and lateral faces.</td>
</tr>
<tr>
<td></td>
<td>Hip: Innominate, acetabulum, and proximal femoral</td>
<td>Necessary prerequisite for fragmentation of hindlimb.</td>
<td>Deep cut marks on femoral head and acetabulum, and occasionally on greater trochanter and lateral non-articular bone around acetabulum.</td>
</tr>
<tr>
<td></td>
<td>Cranium/cervical vertebrae</td>
<td>Likely prerequisite for fragmentation of cranium.</td>
<td>Cut marks on occipital condyles and/or cervical vertebrae near articular bone and perpendicular to connective tissue orientation.</td>
</tr>
</tbody>
</table>

## TERTIARY AGENT & ACTION: HOMININ FRAGMENTATION

| Hammerstone Fragmentation | Fragments limb bones. Creates percussion marks, percussion notches and green fracture edges. Renders some MSH fragments unidentifiable. May disassociate carnivore tooth marks on shafts from disarticulation marks on EPI’s. |

## QUATERNARY AGENT & ACTION: CARNIVORE SCAVENGING

| Carnivore ravaging | Deletes EPI fragments and compact bones. Creates tooth marks, tooth notches and green fracture on MSH’s. Removes evidence of disarticulation and scrap defleshing. |

Figure 4-4. Late hominin access consumption sequence.
Figure 4-5. Cut mark width on elbow portions in cow trials.

Figure 4-6. Cut mark depth on elbow portions in cow trials.
Figure 4-7. Cut mark width on elbow portions in goat trials.

Figure 4-8. Cut mark depth on elbow portions in goat trials.
Figure 4-9. Cut mark count in cow clusters across elbow portions and butchery actions.

Figure 4-10. Area of cow clusters across elbow portions and butchery actions.
Figure 4-11. Median cut mark length in cow clusters across elbow portions and butchery actions.

Figure 4-12. Standard deviation of cut mark length in cow clusters across elbow portions and butchery actions.
Figure 4-13. Standard deviation of cut mark angle in cow clusters across elbow portions and butchery actions.

Figure 4-14. Cut mark count in cow clusters across elbow portions, skeletal locations and butchery actions.
Figure 4-15. Area of cow clusters across elbow portions, skeletal locations and butchery actions.

Figure 4-16. Median cut mark length in cow clusters across elbow portions, skeletal locations and butchery actions.
Figure 4-17. Standard deviation of cut mark length in cow clusters across elbow portions, skeletal locations and butchery actions.

Figure 4-18. Standard deviation of cut mark angle in cow clusters across elbow portions, skeletal locations and butchery actions.
Figure 4-19. Cut mark count in goat clusters across elbow portions and butchery actions.

Figure 4-20. Area of goat clusters across elbow portions and butchery actions.
Figure 4-21. Median cut mark length for goat clusters across elbow portions and butchery actions.

Figure 4-22. Standard deviation of cut mark length for goat clusters across elbow portions and butchery actions.
Figure 4-23. Standard deviation of cut mark angle for goat clusters across elbow portions and butchery actions.

Figure 4-24. Cut mark count in goat clusters across elbow portions, skeletal locations and butchery actions.
Figure 4-25. Area of goat clusters across elbow portions, skeletal locations and butchery actions.

Figure 4-26. Median cut mark length in goat clusters across elbow portions, skeletal locations and butchery actions.
Figure 4-27. Standard deviation of cut mark length in goat clusters across elbow portions, skeletal locations and butchery actions.

Figure 4-28. Standard deviation of cut mark angle in goat clusters across elbow portions, skeletal locations and butchery actions.
Table 4-1
Proportion of trials bearing clusters

<table>
<thead>
<tr>
<th>Bone ID</th>
<th>portion ID</th>
<th>cow Deflesh</th>
<th>cow Disartic</th>
<th>goat Deflesh</th>
<th>goat Disartic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humerus</td>
<td>DNEF</td>
<td>0.625</td>
<td>0.5</td>
<td>0.875</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>DEPI non-artic</td>
<td>0.125</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>DEPI</td>
<td>0</td>
<td>0.75</td>
<td>0.125</td>
<td>0.5</td>
</tr>
<tr>
<td>Radius</td>
<td>PEPI non-artic</td>
<td>0.375</td>
<td>0.5</td>
<td>0.125</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>PNEF</td>
<td>0.75</td>
<td>0</td>
<td>0.75</td>
<td>0.5</td>
</tr>
<tr>
<td>Ulna</td>
<td>olecranon</td>
<td>1</td>
<td>0.75</td>
<td>0.625</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>spine</td>
<td>0.75</td>
<td>0.25</td>
<td>0.875</td>
<td>0</td>
</tr>
</tbody>
</table>
Chapter 5: Zooarchaeological analysis of the Okote Member, Koobi Fora, Kenya

Abstract

The Okote Member at Koobi Fora, Kenya contains three large, well-preserved zooarchaeological assemblages with abundant butchery evidence, relatively few carnivore tooth marks and a lack of associated lithic artifacts. Pobiner presented the initial analysis of these assemblages (2007, Pobiner et al., 2008), concluding from her anatomical cut mark diagnosis and the assemblage scale proportion of butchered specimens that hominins’ enjoyed primary access to carcasses. The modified bone sub-assemblages from GaJi 14, FwJj 14A and B, are re-analyzed here using two experimentally derived models. Butchery actions that comprise early, middle and late stages of hominin carcass consumption are defined respectively as (1) defleshing limbs, (2) defleshing the cranial and thoracic skeleton, and (3) fragmentation and perquisite metapodial tendon removal and element disarticulation. In each assemblage, NISP and MNE counts within large and small animal groups are explored to evaluate whether hominins conducted butchery actions that represent early access to complete carcass parts and whether late stage butchery represents scavenged carcass access or complete consumption of meat and marrow. Cut mark clusters on elbow specimens were diagnosed to a defleshing or disarticulation butchery action to identify whether each element represents hominins’ early access to meat or later access to marrow. All three assemblages indicate early access to flesh of large and small mammals and consumption of bone marrow. But FwJj 14A stands out for its relative abundance of small animal
butchery and consumption of marginal flesh scraps from the thorax and head. This supports an interpretation of *Homo erectus* as a carnivorous generalist.

**Introduction to the Okote Member at Koobi Fora**

The Koobi Fora region occupies the northeastern portion of the Turkana Basin in northern Kenya. The geology of this region has been well documented and chronometrically dated via waterlain tuffaceous horizons distributed throughout the members of the Koobi Fora Formation (Brown and Feibel, 1985, 1986, 1991, Feibel, 1988, McDougall, *et al.*, 2006). The Turkana Basin records an alternating paleogeographic history dominated by the paleo-lake Lorenyang and the proto-Omo river which switched between an axial channel and system of braided channels (Quinn, 2007, Rogers *et al.*, 1994). The Okote member is bounded by the Okote tuff complex, which contains multiple tuffs that are laterally discontinuous in East Turkana and are dated to 1.6 - 1.56 Ma, and the Chari tuff dated to 1.38 Ma (Brown *et al.*, 2006). The Koobi Fora region was characterized by a meandering proto-Omo channel with smaller distributaries draining the Eastern basin margin or branching off of the axial channel (Quinn *et al.*, 2007).

Koobi Fora is divided into three paleogeographic regions based on modern topography, the Koobi Fora Ridge, Ileret and the Karari Ridge, all of which preserve archaeological traces during the Okote Member (Figure 5-1, Bunn, 1994, Harris and Isaac, 1997). Paleoenvironmental reconstruction based on pedogenic carbonate analysis suggests that the Okote member represented open habitat expansion resulting in mosaic
low-tree shrub savanna ecotones through time and across the sub-regions in East Turkana (Quinn et al., 2007). Sub-regional paleohabitat differences are reconstructed based on inferred water budget related to proximity to the axial channel in the basin and larger distributaries, therefore the Karari Ridge is reconstructed to contain more wooded paleohabitats compared to savanna woodland or shrubland reconstructions for Ileret and the Koobi Fora Ridge (Quinn et al., 2007).

Paleovegetation differences should be viewed in context with the total affordances that impacted hominin life in each of these sub-regions (Blumenschine and Peters, 1998). In addition to vegetation, which provides food resources and refuge, sources of water and lithic materials along with predation risk and competition from the carnivore guild are likely to be key components of the landscape facets within which Okote member hominins foraged. These paleohabitat factors form the paleoenvironmental context that from which inferences about the tool-assisted foraging for carcass resources by Okote Member hominins are drawn.

Stone raw material is transported into the Koobi Fora region in different ways. The Surgei Plateau defines the eastern basin margin and provided the primary raw material for clasts transported by into the basin during the Okote including basalts, phonolites, and cherts (Braun et al., 2008). The Kokoi Horst is a large uplifted basaltic block located near the Karari Ridge, but it emerged after the Koobi Fora Formation was deposited, and therefore was not a source of stone tool raw materials during the Okote Member (Feibel, 1988). The proto-Omo channel carries additional exotic raw materials like quartzite and chert from its Ethiopian catchment area, but due to choking of the main channel by frequent pyroclastic events during Okote times in Ethiopia, this river assumed
a braided channel geomorphology, depositing conglomerate beds of smaller average clast size and perhaps a more frequently changing location (Braun et al., 2008).

The distribution of lithic raw material on the paleolandscape is incorporated into a sub-regional scale foraging strategy which identifies the abundance of locally available cobble-sized lithic material in basin margin drainage channel deposits near archaeological occurrences on the Karari Ridge, but a distance of between 5 and 20 kilometers to the nearest lithic source from sites located on the Koobi Fora Ridge and at Ilaret. This leads Bunn (1994) to describe a foraging strategy where Okote hominins transported large core tools from their sites of manufacture into paleohabitats lacking raw material and butchered animals with these tools. This hypothesis will be discussed in detail below.

The mammalian faunal suite during the Okote Member is similar to the modern East African fauna that inhabits a wooded savanna mosaic environment, and this ecological structure was probably put in place by a turnover event in extinctions that occurred around 1.8 Ma (Behrensmeyer et al., 1997, Harris, 1991). Recent extinctions of the sabretooth cats and larger hyenas introduced the modern carnivore guild during the Okote, leaving lions, leopards and cheetahs as the primary flesh specialists, and spotted, striped and brown hyenas as secondary consumers of mammalian carcasses (Turner, 1988, Van Valkenburgh, 2001).

Traditionally, two distinct hominin taxa, Homo erectus and Paranthropus boisei were thought to have shared this landscape with other large mammals (e.g. Leakey and Leakey, 1977, Leakey and Walker, 1988, Walker and Leakey, 1993). However, the recently discovered ER 42703 partial maxilla, assigned to Homo habilis, and the slightly older cranium ER 42700 described as a small Homo erectus, both of which are dated to
the end of the Okote Member from the Ileret region of East Turkana, suggest that two species of the genus *Homo* coexisted near Ileret around 1.5 Ma (Spoor *et al*., 2007). It is difficult to resolve which hominin taxon generated the Okote Member butchered bone sites discussed here since both species are known to create developed Oldowan tools and butchered bone assemblages. Although it is difficult to compare paleoecological interpretations across very different habitats, the Okote butchery sites discussed below are characterized by very little evidence of carnivore activity, which stands in contrast to FLK *Zinjanthropus*, where *Homo habilis* probably scavenged from large carnivores (Blumenschine, 1995).

The robust masticatory apparatus in *P. boisei* is interpreted as an adaptation for processing tough plant foods hard objects like seeds and nuts or denser fibrous tubers and root stocks (Walker, 1981), and isotopic analysis of tooth enamel leads to similar dietary reconstructions (van der Merwe *et al*., 2008). Therefore this dissertation follows the traditional assumption that *P. boisei* did not manufacture and stone tools to butcher carcasses. However, recent reconstructions of postcranial morphology and their implied body size suggest that the taxon may not have been as diminutive as previously suggested (Wood and Constantino, 2007).

The recent discovery of alleged butchered bone from 3.7 Ma in Ethiopia, and the earliest confirmed Oldowan butchery traces at around 2.6 Ma highlight the deep antiquity that tool-assisted carnivory has in the hominin lineage, (deHeinzelin *et al*., 1999, Dominguez-Rodrigo *et al*., 2005, 2010, McPherron *et al*., 2010) and reminds us that we must weight multiple lines of paleoecological evidence when inferring which hominin
taxa manufactured stone tools or contributed to the Okote Member zooarchaeological assemblages. Only future discoveries will reveal these answers.

*Homo erectus* was first defined from fossils discovered in Southeastern Asia, and is now recognized as the first hominin taxon to disperse widely throughout the Old World (Anton, 2003). Cranially, *H. erectus* displays an increased brain size compared to earlier *Homo*, slightly reduced dentition and facial prognathism, but its most striking derived feature is its fully modern body size (Walker and Leakey, 1993, Brown *et al.*, 1985). As in living mammals, particularly primates, home range size is positively associated with body size and is a function of the geographic area necessary to collect food resources. This relationship is suggested by some to cause the intercontinental dispersal of *H. erectus* during the Early Pleistocene, and on a more local scale is also linked to a hypothesized day range increase (Anton *et al.*, 2002, Leonard and Robertson, 2000). In general, the modern stature of *H. erectus* leads to their characterization of a species-scale foraging strategy that involved increased mobility, which implies movement through more diverse paleohabitats compared to earlier species of genus *Homo*. In fact, endurance running was even recently debated as a foraging strategy with adaptive evolutionary implications for *H. erectus* (Bramble and Lieberman, 2004, Pickering and Bunn, 2007).

The expanding home range is also related to a need for acquiring high-quality dietary resources in order to supply nutrients necessary to grow and maintain expensive tissues such as the brain (Aiello and Wells, 2002, Aiello and Wheeler, 1995).

Regardless of the hypothesized interplay of behavioral, ecological and biological factors that influenced hominin foraging, archaeological evidence in the Okote Member supports behavioral predictions of large geographic ranges and foraging activities
throughout different savanna mosaic ecotones. As the archaeological analysis of Braun et al. (2008) indicates, the transition from the underlying KBS Member to the Okote Member includes the manufacture of Developed Oldowan stone tools from raw materials that were transported across greater distances. This echoes the previous findings of Rogers et al. (1994) that reported archaeological occurrences in the Okote Member in a diversity of fluvial contexts, in contrast to earlier KBS Member sites that were spatially associated with proximity to the axial channel or large drainages that provided stone raw material sources. These ideas may be complicated by the paleogeographic reconstruction of Okote Member times, which saw geologically frequent transitions between a large axial channel and a series of braided streams. Regardless, the main drainage system was choked with tuffaceous sediment introduced by Ethiopian volcanic events, which altered the axial drainage pattern and affected the location of riparian and upland habitats on a relatively short time scale. The exact timing of these geomorphological transitions is unknown, but it seems that the location of braided channels and their relatively closed habitats would not undergo dramatic geographical displacement during individual hominins’ lifetimes. Whereas the location of gravel bars providing lithic material in the main drainage system may change slightly, streams draining the basin margin were probably minimally affected by the sediments that choked the main channel, and their raw material sources remained relatively fixed as well. In sum, this suggests that during Okote Member times, the Koobi Fora region contained a variety of wooded savanna ecotones, with relatively predictable stone tool source material locations on a timescale relevant to an individual organism.
Bunn (1981, 1994) attempts the most detailed reconstruction of a regional foraging strategy of tool transport and carcass butchery for Okote Member hominins. Based on archaeological traces found on the Karari Ridge, Koobi Fora Ridge and Ileret (discovered before the Okote sites analyzed here), Bunn describes a foraging strategy where scarce stone raw material was conserved as hominins carried large core tools from their sources into areas of the landscape that lacked stone raw material and used these tools during butchery, especially when processing large animal carcasses.

Bunn (1994) reaches the conclusion that tools were curated across the landscape because discarded stone tools have not been found in the Koobi Fora Ridge and Ileret areas where raw material sources in basin margin drainage gravel bars are between 5 and 20 kilometers away. But abundant evidence of their use is recorded in assemblages of butchered bone. Additionally, Bunn suggests that large core tool use was a feature of this foraging strategy both because discarded flakes were never discovered, and because core tools are sometimes suggested to be more efficient tools for large animal butchery (Jones, 1981). Further, Bunn interprets wide, shallow cut marks on some of these bones as evidence of core tool use.

This behavioral reconstruction is a parsimonious explanation, but it is based on a variety of inferences, some of which are called into question by the evidence presented earlier in this dissertation. Regardless, this hypothesis can be reevaluated in light of more recent and extensive zooarchaeological findings at Koobi Fora. While the lack of stone tools is not definite evidence of their curation, it is telling that discarded tools or evidence of flaking debris have never been discovered despite extensive survey. Likewise the assemblages from the regions discussed in this chapter did not preserve any
microdebitage from in situ tool manufacture despite careful excavation (Pobiner et al. 2008). However, the conclusion that core tools were used for butchery cannot be supported with the absence of discarded tools since wide and shallow cut marks can be created by both cores and flake tools.

Previously published Okote zooarchaeological analyses

Pobiner (2007, Pobiner et al., 2008) provides the primary description, zooarchaeological and taphonomic analysis, and paleogeographical reconstruction of three butchered bone assemblages that occur in Okote Member sediments at Koobi Fora. The excavations of FwJj 14A and B and GaJi 14 were a product of the collective effort of Koobi Fora Research Project team members over many years, and I participated in these excavations during six summer field seasons. In this collaborative spirit, I summarize Pobiner’s site descriptions and paleoecological conclusions and build on these efforts. I propose a novel analytical approach that interprets butchery traces on specimens in these assemblages and compliments existing reconstructions of Homo erectus’ foraging behavior during the Okote Member.

All three sites, dated to roughly 1.5 Ma, are fragmentary bone assemblages with well preserved cortical surfaces that bear abundant evidence of hominin butchery and are not associated with in situ lithic artifacts (Pobiner, 2007, Pobiner et al., 2008).

GaJi 14
This zooarchaeological assemblage occurs in Area 103 on the Koobi Fora Ridge and is deposited in channel sands that occur near the KBS-Okote member boundary. It is overlain by the lower Koobi Fora tuff (1.49 Ma) and lies 15 meters above the arenaceous marker bed A6 which is dated by sedimentation rate extrapolation to 1.62 Ma. The lithology of the site indicates that the assemblage was buried by a low-gradient stream draining into a marshy lake shore setting. Paleogeographic reconstructions of the Turkana Basin suggest that once channels draining the Eastern basin margin encountered a low-gradient terrain, they may have fed swampy mini-lakes (Quinn et al., 2007). This site was originally excavated as two distinct occurrences, GaJi 14 A and B, which were later combined since they were shown to represent the same depositional and temporal context (see Rogers et al., 2004 and Pobiner, 2007). The minimum number of elements and individuals were calculated for these different assemblages before they were merged, and without reanalysis of the specimens these estimates are difficult to recalculate. Therefore, these estimates probably inflate the minimum numbers of elements and individuals in the total assemblage.

The taxonomic list for GaJi 14 (Table 5-1, from Pobiner et al., 2008: Table 1) includes wet-loving taxa like turtle, hippos including Hexaprotodon protamphibius, the reduncine Kobus sigmoidalis and the swamp dwelling cane rat (Thryonomys swinderianus), along with a browsing tragelaphine bovid, but also includes open-environment taxa like giraffids, equids, and Alcelaphines.

At GaJi 14 around 35% of bone specimens are 2 to 3 centimeters in size, which indicates that minimal fluvial transport affected the assemblage. Likewise, most specimens are weathering stage 0 (Behrensmeyer, 1978) indicating relatively rapid burial,
and 84% of specimens have surfaces whose area is obscured by less than 25% of adhering matrix or surface damage. However, the assemblage is highly fragmented. Long bone circumference is skewed toward incomplete shafts, with 59% of long bones having a quarter or less of their original circumference, and another 24% of long bones preserve between a quarter and half of their original circumference. In general, 74% of specimens could not be identified even to mammalian size class (Bunn, 1982) because of the high degree of fragmentation.

The total number of faunal specimens is 2087, but the number of bones specimens examined for bone surface modification by Pobiner is 1659. When all of these specimens are examined the minimum number of individuals is estimated to be 21 mammals, the majority of which are size class 3, although this value is probably inflates since MNI was calculated separately for the A and B sub-assemblages. Midshafts greatly outnumber epiphyseal fragments and the epiphysis to shaft ratio across all size categories is 0.17.

Butchery marks are present on 6% of specimens examined, with 86 cut-marked, 13 percussion-marked, four cut- and percussion-marked specimens, and one tooth marked in Pobiner’s analysis of the assemblage.

_FwJf 14A_

This assemblage is located in area 1a in the Ileret sub-region and is deposited in a clayey mudstone that was indurated with calcium carbonate, suggesting a distal floodplain context. It occurs just above the Northern Ileret Tuff, which is dated to 1.52 Ma (Brown _et al._, 2006).
FwJj 14A includes aquatic non-mammalian fauna, and fauna adapted to closed and wet environments like reduncine bovids including *Kobus kob*, *Hexaprotodon protamphibius*, and the cane rat (Table 1). A few unidentified suid individuals were and an aepycerotini bovid are probable browsers, and occur along with open habitat adapted taxa including alcelaphines and an unknown equid. The elephant specimens are all fragmentary teeth and most likely belong to *Elephas recki*.

At FwJj 14A around 45% of the assemblages consists of bone specimens between 2 and 3 centimeters in size, suggesting minimal winnowing. Most specimens are not weathered, suggesting rapid burial and 72% of specimens have bone surfaces that are greater than three quarters unaffected by cortical matrix or chemical dissolution. Long bone circumference is skewed toward incomplete shafts, with 75% of long bones having a quarter or less of their original circumference, and another 18% of long bones preserve between a quarter and half of their original circumference. Because of intense fragmentation, nearly 65% of the fragments could not be identified even to mammalian size class.

The total number of faunal specimens is 2170 and 1653 of these were bones that were examined for surface modifications. These fragments represent a MNI of 14 mammals, the majority of which are size class 3. Midshafts greatly outnumber epiphyseal fragments and the epiphysis to shaft ratio across all size categories is 0.14.

In Pobiner’s analysis butchery marks are present on 9% of the specimens examined. One hundred and twenty four specimens are cut-marked, 17 are percussion marked and two display both cut- and percussion marks. Only five specimens have carnivore tooth marks.
This assemblage is situated three meters above FwJj 14A, and is extrapolated to be around 1.5 Ma in age, and represents a different depositional context. Butchered bone was deposited on top of a clayey mud ground surface and as the ancient channel aggraded, the archaeological material was covered by tuffaceous silty sand, indicating the bank of a broad, shallow stream.

The mammalian faunal list for FwJj 14B is generally similar to FwJj 14A, in that it contains reduncine bovids and a hippo, but adds an antilopine to the grazing and/or open adapted taxa which include alcelaphine and hippotragine bovids but lack equids. Interestingly a cercopithecine monkey individual suggests the presence of gallery forest.

At FwJj 14B nearly 50% of specimens are between 2 and 3 centimeters in size, indicating minimal winnowing. Most specimens are not weathered indicating relatively rapid burial of the assemblage, and 92% of specimens have more than three quarters of unaffected cortical surface. Most long bones are highly fragmented, as indicated by 74% of long bone specimens that preserve less than a quarter of their original shaft circumference. Since this assemblage is so fragmentary, 84% of specimens could not even be identified to mammalian size class.

The total number of faunal specimens is 1782, and 1713 of these bones were examined for surface modification. Together these fragments represent 13 mammal individuals, the majority of which are size class 3. Midshafts greatly outnumber epiphyseal fragments and the epiphysis to shaft ratio across all size categories is 0.07.
In Pobiner’s analysis, butchery marks are present on 5% of the examined assemblage, which are divided into 63 cut-marked specimens, five percussion-marked specimens and five specimens that bear traces of slicing and percussion. No carnivore tooth marks occur in the assemblage.

Pobiner et al.’s taphonomic conclusions about Okote Member zooarchaeology

Pobiner et al. (2008) interpret taphonomic traces of butchery on different scales including the assemblage, bone elements and portions, and specimens that represent individual animals, which is a useful analytical strategy since it explores the ways that different taphonomic processes affect interpretations of behavior from bone assemblages and describes data on scales which can be compared with a diversity of contemporary taphonomic experiments and observations.

On the level of the assemblage, proportions of butchered specimens in different analytical categories are examined. Hominin’s early access is predicted to impart cut marks across most portions of the skeleton, which after fragmentation is transformed into a high frequency of cut-marked specimens in an assemblage (Blumenschine, 1995, Capaldo, 1998, Dominguez-Rodrigo, 1997, Selvaggio, 1998). Compared to sequential actualistic models all three Okote assemblages have very high proportions of butchered specimens and very low proportions of tooth-marked specimens. Likewise, early hominin carcass access predicts butchery of high-yield carcass parts (Blumenschine, 1986). Cut marks are indeed very common on long bone midshafts, which is often linked with defleshing, but other bone portions like epiphyses are severely underrepresented in the
assemblage. Further, when element abundance in the assemblage and the proportion of skeletal elements that possess butchery traces are examined in relation to different utility indices (meat availability and MGUI from Binford, 1978, and carcass consumption sequence from Blumenschine, 1986), no correlation emerges.

However, these relationships are easily influenced by changes in the skeletal element and portion profiles in the assemblage that depend on a variety of factors including carnivore ravaging, hominin carcass transport, density-mediated destruction and random chance. For example, the proportion of butchered specimens identified by Pobiner is closest to the carnivore-hominin-carnivore model, but when examining other lines of evidence, this hypothesis can be refuted, because carnivore tooth marks are nearly absent in the Okote Member sites. Pobiner et al. acknowledge the tenuous nature of these explanations that are drawn from data on the assemblage scale. In fact, butchery traces on cranial remains, typically considered a low-ranking carcass resource, exemplify this problem;

“The relatively high proportion of cut marks on crania and mandibles, including hyoids, compared with their low rank may indicate either a higher encounter rate of heads, a higher preference for processing heads, a higher survival rate for heads, or more densely distributed cut marking on heads and more thorough fragmentation prior to or after fossilization (e.g., recent break rates)” (Pobiner et al., 2008:115).

The presence and location of butchery marks on different specimens from all three assemblages are also described by Pobiner, but in this context butchery evidence is summarized by skeletal element, and specifies animal size class and taxon when they can be determined. Based on existing butchery observations (Binford, 1981, Nilssen, 2000, Pobiner and Braun, 2005, Wilson, 1982), cut marks on limb elements and girdles are attributed to defleshing, with the exception of metapodials, whose cut marks are
associated with skinning, disarticulation or periosteum removal, and disarticulation marks are described on carpals and tarsals. Three butchered hyoid specimens occur in FwJj 14B, and this rarely reported element suggests tongue removal. The majority of cut marks that occur on epiphyses in all three assemblages are found on metapodials and are attributed to foot disarticulation. Other epiphyseal cut marks are present on elbow specimens including size 2 and 3 ulnae with cut marks on their posterior aspects which are suggested to indicate skinning or filleting, and a proximal radius of a size 3 bovid with medial/anterior cut marks distal of the epiphysis, which are taken as evidence of filleting or defleshing (cf. Nilssen, 2000). These butchery action interpretations can be expanded with actualistic data presented in this dissertation that link cut mark location and organizational attributes of cut mark clusters to skinning, defleshing or disarticulation.

Carnivore tooth marks are nearly absent in the Okote assemblages. No tooth marks were found in FwJj 14B. In FwJj 14A, Pobiner et al. report three tooth marked specimens, two of which, a size 3 tibia midshaft and size 3 long bone midshaft have both cut marks and tooth marks. Since these marks don’t overlap, and tooth marks occur near a fracture edge, hominins are interpreted by Pobiner et al. to have defleshed these bones that were later fragmented by scavenging carnivores. Interestingly, at GaJi 14 one specimen bears both cut marks and carnivore tooth marks, which resemble crocodile tooth marks. The co-occurrence of taphonomic traces of these different agents has never been documented before, but seems to suggest primary hominin processing followed by crocodile consumption (Pobiner, 2007, Pobiner et al., 2008).

Percussion marks data is more difficult to interpret in these assemblages since these marks occur on many fewer specimens and are created during fragmentation, which
reduces the identifiability of skeletal elements and may create fragments that are unmarked (Pickering and Egeland, 2006). For example, only five of 28 percussion-marked specimens at FwJj 14A can be identified to element. The presence of percussion marks as evidence of marrow processing is interpreted with respect to the marrow yield of upper, intermediate and lower limb elements when this can be identified. The samples of percussion marks are very small from each site, and are difficult to interpret conclusively since they occur on upper, intermediate and lower limb elements. This leads to the conclusion that despite their relatively low marrow yield, lower limb bones were fragmented, indicating complete consumption of carcass resources. Despite the small number of percussion-marked specimens, nearly every specimen is fragmentary in these assemblages and carnivore tooth marks are nearly absent, leading Pobiner et al. to examine the abundance of fragmented elements with respect to their marrow contents to assess whether the assemblages in general represent fragmentation of high or low ranking marrow bearing elements. By examining the rank-order correlation of NISP of different elements and these elements’ marrow yield, the authors find more fragments of higher-ranked long bones at GaJi 14 and possibly FwJj 14A, suggesting that hominins “generally broke open and/or transported limb bones according to their rank order of marrow yield” (Pobiner et al. 2008:113). The authors are explicit about the underlying assumption that hominins must be the sole agent of fragmentation, but whether this relationship is appropriately tested with NISP data is a matter of debate, since in these assemblages NISP is affected by both green and dry breakage and we still lack a strong inferential model for understanding how different skeletal elements are transformed into hammerstone-broken fragments.
Pobiner et al. also present an analysis of how butchered specimens represent individual animals that are stratified across animal size class and taxon when this information can be identified. At GaJi 14 nine individuals ranging from size 1 to 5/6 were butchered. These include seven bovids: one mature size 2, one immature size 2, one size 2a/3, one size 3, one size 3a, and a size 3b/4. Bones of a size 2/3 suid were butchered as well as a size 3b/4 juvenile hippo, and an unidentified size 5/6 mammal’s ilium. FwJj 14A preserves butchered bone from nine individuals over size classes 1 to 4 compared to the assemblage MNI of 14. These include six bovids: one size 2/3a, a size 3a, and four size 3 individuals. Three suids, two size 2 and one size 3a individual’s butchered bones were recovered. At least one size 4/5 hippopotamus was butchered. At FwJj 14B at least 11 individuals ranging from size 1 to 3b/4 were butchered out of the assemblage MNI of 13. A size 1 Cercopithecus monkey humerus was butchered. Bones of seven bovids were butchered: one size 2, one size 2/3a, one size 3a, three size 3, including two alcelaphines and a hippotragine, and a size 3b/4 bovid. Bones of three suids were butchered: a size 3, 3a and 3b.

This analysis includes MNI estimates using cut-marked specimens which are compared to the MNI estimates drawn from the entire assemblage. The authors recognize that MNI estimates may mistakenly include bones from different individuals and at times individuals reconstructed in the assemblage that are identified to species based on teeth may even include long bones from different genera or higher taxa. However, this technique is a valuable analytical tool since it examines butchery of individual animals. Foraging hominins encountered individual animals and processed their carcasses so it is useful to examine butchery on this scale, since differences in animal size class and taxon
imply distinct paleoecological contexts. However, as noted by the authors, it is difficult to determine whether whole animals were butchered on-site or if smaller segments of their carcasses were transported to the sites and then butchered. Again, the interpretive problems intrinsic to reconstructing individual animals come from the fragmentary nature of bone assemblages.

Regardless of the interpretive uncertainty that plagues any archaeological assessment of MNI, examining the individual animals butchered indicates that Okote member hominins were consuming carcasses from a wide variety of taxa that include small arboreal primates, bovids that prefer open and closed habitats, and large animals like hippos.

Pobiner et al. highlight an important analytical problem for interpretations of fragmentary butchery assemblages when they explain “that the lack of cut marks on limb epiphyses is related to the general lack of limb epiphyses at these sites” (2008:110). At first, this statement seems somewhat trivial, but it is a clear reminder to bear in mind that archaeological materials offer an incomplete record of past behavior, and our analytical techniques may bias interpretations when they ignore missing evidence or assign an untestable behavioral meaning to missing data (Gifford-Gonzalez, 1991).

**Analysis of Okote Member butchery traces**

**Methods**

I conducted a re-analysis of the butchered specimens from GaJi 14, FwJj 14 A and
B previously analyzed by Briana Pobiner (2007, Pobiner et al., 2008) as part of my doctoral dissertation to explore how cut mark traces can be used to interpret butchery evidence and infer the ecological position of the hominins that consumed these carcasses. I examined all butchered specimens from the three Okote Member sites, compiling my own taxonomic and taphonomic identifications. I was able to use the modern skeletal reference collection at the National Museums of Kenya Archaeology Division and refer to excavation notes, site catalogs, and unpublished identifications from Briana Pobiner (personal communication, 2006) as a reference for taxonomic identification, but these identifications and interpretations of bone surface modification derive from my own conclusions. I did check for agreement between myself and Pobiner’s taxonomic and taphonomic identifications, and in most cases our analyses matched. In some instances our identifications were in disagreement, but these instances were relatively uncommon, and they will be explained below. This is to be expected since we were both trained under the tutelage of Dr. Robert Blumenschine (see Blumenschine et al., 1996).

Each butchered specimen was identified to the most precise taxonomic level possible, along with skeletal element, portion following the proximal and distal epiphysis (PEPI and DEPI), proximal and distal near-epiphysis (PNEF and DNEF) and midshaft (MSH) long bone coding conventions (see Pobiner, 2007).

Following the methodology for identifying bone surface modifications, the entirely of a specimen was examined with strong, low-incidence light from a variety of directions using hand lenses at 10 and 16 power magnification. All bone surface modifications were recorded including cut, scrape (Bunn, 1981, Potts and Shipman, 1981), and percussion marks and striae (Blumenschine and Selvaggio, 1988), carnivore tooth pits and scores
(Binord, 1981) rodent gnawing, root etching, sediment abrasion (see Fisher, 1995), and bioerosion (Blumenschine et al., 2007, Dominguez-Rodrigo and Barba, 2006). Indeterminate marks, pits and striae were recorded as such and not assigned to a taphonomic agent. Weathering stage was recorded following Behrensmeyer (1978). Qualitative descriptions of the taphonomic traces that were present on analyzed specimens are listed in Appendix B.

My archaeological analysis first describes the butchery traces on individual specimens, exploring the evidence for butchery within categories of animal size class, taxon and skeletal region. Tables 5-2, 5-3 and 5-4 list the butchered specimens from GaJi 14, FwJj 14A and FwJj 14B that I identified, examined for bone modification and photographed in the NMK-AD in October of 2006.

**Butchery stage analysis**

The location of cut marks on specific skeletal elements was used to identify whether a specimen was defleshed, disarticulated or skinned, or some combination of those actions, following results in Chapters 2 and 3. Cut marks on epiphyseal portions of long bones represent disarticulation and cut marks on shaft portions are interpreted as evidence of defleshing. Cut marks on metapodial shafts represent filleting of the anterior and posterior tendon bundles since these regions bear no muscle tissue. Deep, transversely oriented cut marks on near-epiphyseal regions of the metapodials are interpreted as evidence of skinning. Cut marks on ribs indicate defleshing when they occur on the lateral surface and evisceration when they occur on the medial surface. Any
percussion marks or striae are interpreted as evidence of fragmentation. Carnivore tooth marking is typically rare in these assemblages, and these specimens are included in this analysis only when they also preserve butchery marks.

Based on the carcass consumption sequence observed by Blumenschine (1986), I ranked butchery of different carcass segments into early, middle and late categories of hominin access (Table 5-5). If hominins had late access to a carcass as if they were practicing a scavenging strategy they would only conduct late stage butchery actions, which include disarticulation of elements, metapodial tendon removal and fragmentation for within-bone nutrients. When hominins accessed carcasses in the middle of the consumption sequence, most of the limb flesh would be consumed, so defleshing the ribs, head, and possible scraps on long bones is predicted along with consumption of the thoracic viscera. If hominins had early access to a carcass (or parts of carcasses) that was relatively complete they would be able to deflesh the hindquarters and forequarters, including the upper and intermediate limb elements.

The presence of flesh scraps that remain after primary carnivore consumption is a complicating factor for this hypothetical model of the butchery sequence. As Chapters 2 and 3 show, it is not possible to distinguish cut marks produced when large muscles are defleshed versus those produced during the removal of small scraps based on cut mark size or cluster geometry, and these marks may occur anywhere on the appendicular skeleton. Therefore it may be difficult to determine whether cut marks represent early hominin access to fully fleshed carcasses or middle-stage access where flesh scraps were removed with stone tools. In some cases, defleshing carnivore tooth marks may help resolve whether hominins butchered scraps from carnivore kills, but the marks of
multiple agents may not always be present. Regardless, when hominins remove any amount of flesh from a carcass, even when these are scraps of rib flesh or scraps around limb joints, they are successfully competing with flesh-specialist carnivores and are not limited to a late access ecological role where only within-bone carcass resources remain. Therefore in this hypothetical model, any evidence of limb element defleshing is interpreted as early access.

Specimens were assigned to an early, middle or late stage of hominin consumption based on the presence of specific cut mark traces on a particular skeletal element. If a specimen preserved evidence of both early and late access, which was this case if it had both defleshing and disarticulation cut marks or fragmentation traces, it was counted in the early category. This method examines only the butchered specimens that could be identified at least to mammal size class, and essentially is a count of the butchered NISP in each stage of hominin carcass processing. Size 1 and 2 mammals are grouped into the small category and mammals size 3 and above are grouped into a large category. When a range of sizes is listed the specimen is counted in the larger category.

Any count of zooarchaeological specimens in a fragmentary assemblage must be interpreted cautiously because specimen abundance may truly reflect hominin behavior or exist as an artifact of density-mediated destructive processes (Lyman, 2004). These equifinalities are typically evaluated by examining the correlation of NISP and bone density or utility indices (Bar-Oz and Munro, 2004, Grayson and Frey, 2004). However, unlike traditional skeletal part profiles, each sequential butchery stage defines a more general analytical category that includes different skeletal elements. These distinct elements each have their own density or utility values and therefore, each stage is not
severely biased by taphonomic processes that delete less dense elements. Still, this method may be affected by the under-representation of less-dense skeletal portions. For example, disarticulation primarily imparts cut marks onto epiphyseal portions, which are also least likely to survive various density-mediated processes of destruction. But again, inclusion of multiple skeletal elements in each consumption stage helps counter this bias, since for example, the distal humerus bears evidence of both defleshing and disarticulation and is one of the densest bone portions. Likewise, early, middle and late butchery stages each introduce butchery marks across the entire skeleton. The early stage of defleshing primarily cut-marks long bone midshafts, whereas middle stage defleshing affects ribs, cranial and mandibular specimens, and late stage butchery cut-marks limb bone epiphyses and metapodial shafts and creates percussion marks on the shafts of all long bones and cranial specimens. So despite the reduced abundance of less dense skeletal elements and portions, midshafts specimens potentially preserve evidence of each butchery stage (Marean et al., 2004).

Fragmentation is another analytical obstacle when zooarchaeological measurements of specimen abundance are evaluated, so a minimum number of elements (MNE) is calculated for the butchered assemblage, and the specimens that represent one element are evaluated with respect to the presence of early, middle or late stage butchery actions. This also allows a comparison between NISP and MNE counts in each butchery stage. If the relative relationship of early and late butchery evidence changes between these two analytical scales, fragmentation may seriously distort interpretations of carcass access in the assemblage. This happens because fragmentation may inflate the NISP of butchered specimens which are grouped into a MNE unit, or it may collapse specimens of the same
element that have early and late stage butchery traces into one MNE unit, which would be counted as an early stage element.

In sum, this technique is meant to explore the presence or absence of early and late access butchery action traces in an assemblage. Evaluating how common these ecological strategies were in hominin foraging strategies is more difficult based on the uncertainty inherent to zooarchaeological analysis, but if both MNE and NISP-scale examinations show the same relative pattern of abundance, this suggests that hominin behavior, and not density-mediated taphonomic processes structured these assemblages. Regardless, it is important to document whether hominins enjoyed early access to carcasses, were limited to scavenging behavior, or practiced a more flexible foraging strategy, and importantly, how these ecological modes changed in response to prey size.

**Elbow cluster analysis**

An analysis of butchered elbow specimens is presented to identify whether individual specimens preserve evidence of defleshing. As demonstrated in chapter 4, experimental butchery evidence shows that the elbow is likely to be cut-marked by defleshing during early stage hominin butchery and by disarticulating the elbow during late stage hominin butchery. Of course defleshing and disarticulation may co-occur during complete consumption, but a specimen that only bears disarticulation marks suggests that hominins did not acquire flesh and therefore acquired that carcass after other consumers.

The geometric attributes of archaeological cut mark clusters on distal humerus,
proximal radius, olecranon process and proximal ulnar shaft specimens are evaluated with respect to the experimental evidence to identify whether the cut marks clusters on each specimen represent defleshing, disarticulation, or both actions.

Cut mark clusters were photographed during analysis of taxonomic and bone surface modifications in the Okote assemblages. The individual cut marks in a cluster were identified with a hand lens and indicated realistically a specimen drawing as a visual record and to ensure every mark and cluster was captured in the photograph. Photographing cut marks can be difficult due to their extremely shallow depth and the curvature of most fossil bone surfaces. This necessitated staging with intense low-incidence light, and the use of a macro feature on a Pentax Optio A10 digital camera at 8 megapixel resolution. When the focal depth of the lens could not capture focused images of all of the cut mark clusters on the entire specimen, multiple photographs were taken without moving the specimen or millimeter scale bar.

Cut mark cluster geometry was recorded and evaluated using the same techniques for the experimental cut mark cluster analysis presented in chapter 3. Digital images were imported into ImageJ 1.41o and the scale bar was measured as a distance in pixels to calibrate the measurement tool. Lines were drawn over each cut mark, the number of cut marks was counted, and each mark’s length (millimeters) and angle (0-180 degrees) relative to the photograph’s axis was measured. True anatomical directions were not recorded because they were often unidentifiable in the small fragmentary fossils. Regardless, cut mark angle is only expressed as the standard deviation of angles in the cluster. The perimeter of the cut mark cluster was drawn around the endpoints of the cut marks that minimized cluster area, and area was calculated in square millimeters.
Archaeological cut mark clusters are compared using cut mark count, cluster area, median cut mark length, standard deviation of cut mark length per cluster and standard deviation of cut mark angle per cluster.

Experimentally generated cluster attributes for each skeletal portion and anatomical direction (Figures 4-9 to 4-28) were used to diagnose whether each cluster on an archaeological specimen fit best with defleshing or disarticulation. An archaeological cluster’s measurement was compared with the range of observed values for the analogous portion and location (e.g. medial face of the humeral DNEF) in the experimental data set. The best fit was determined by the closest match to the defleshing or disarticulation range of values when these butchery actions had distinct ranges. When their interquartile ranges overlapped, the archaeological cluster was assigned to defleshing or disarticulation when it was outside of the interquartile range of the values for the opposite butchery action. Assigning these archaeological cases using confidence intervals based on mean values was not practical due to the small sample of clusters observed at each skeletal location which created very wide, overlapping intervals. When experimental cut marks were never observed at a skeletal location during defleshing or disarticulation, archaeological marks at that location were attributed to the appropriate action. Archaeological clusters that did not fit well within the defleshing and disarticulation comparison were considered indeterminate.

Each cluster was considered when assigning the complete specimen to a butchery action. Indeterminate clusters were ignored and the presence of both defleshing and disarticulation was possible.
Results

GaJi 14

Individual specimen analysis

In general this assemblage bears little direct evidence of carnivore influence and does not suggest that hominins scavenged from defleshed carnivore kills. Tooth-marked specimens are rare; I discovered an additional tooth-marked long bone midshaft of a size 3 mammal (catalog # 672 from GaJi 14B) not reported by Pobiner (2007). It has carnivore tooth marks adjacent to a green fracture edge (Figure 5-2). In addition to this specimen, only one other bone fragments bears traces of non-hominin consumption. However, the relative lack of epiphyseal fragments suggests that bone consumers such as hyenas may have removed most long bone ends before the site was buried. On-site ravaging is not likely to have occurred since it produces many tooth-marked near-epiphyseal and midshaft fragments (Pobiner et al., 2008). The other tooth-marked specimen (catalog # 1034) reported by Pobiner is a size 3 bovid left calcaneum body fragment that also bears two clusters of cut marks (figure 5-3). In addition to the large bisected pit, which is interpreted as a crocodile tooth mark (see Njau and Blumenschine, 2006), this specimen also preserves tooth scores with a shallower u-shaped cross section that resemble typical carnivore tooth scores. It is difficult to resolve whether hominins, crocodiles and carnivorans all fed on this carcass, but the cut marks, which occur on the
anterior-lateral face of the body most likely represent disarticulation of the foot, since the remains of a carcass consumed by crocodiles would not offer much for a scavenging hominin. Further, since crocodiles can produce all of the scores observed on the specimen, the most parsimonious interpretation excludes a terrestrial carnivore. But it is possible that hominins had initial access to the leg, and discarded the disarticulated foot near the lakeshore, where a crocodile attempted to consume it but regurgitated it before scavenging hyenas finally gnawed on it. Or it is possible that hominins scavenged a foot from a carcass defleshed by carnivores, which was then tooth-marked by a crocodile. This specimen highlights the difficulty of inferring the sequence of consumers when bone surface modifications do not overlap.

Butchery traces occur on a variety of elements and suggest that hominins defleshed bones with muscle masses, probably consumed upper thoracic viscera, and engaged in complete consumption as evidenced by butchery of low-ranking carcass parts including phalanges and fragmentation of long bones for their marrow. In total 48 mammal specimens have evidence of hominin butchery. Two cut-marked fish spines occur in the assemblage as well (catalog # 637 is shown for example, Figure 5-4) indicating that aquatic animal resources were also an aspect of Okote Member hominins’ diet (Pobiner, 2007, also see Braun et al., 2010).

A size 2 bovid hemi-mandible horizontal ramus is the only representative of the small size category, and this specimen was both cut marked and percussion marked to access the mandibular nerve. (Figure 5-5 catalog # 1025d). Interestingly, it also possesses a deep, chop-like mark, which in association with other evidence of fragmentation suggests the possibility that a large-sharp edged tool was used as the hammer.
Specimen 1007, a size 3 bovid left metacarpal distal end and shaft also preserves evidence of possible fragmentation with a sharp core tool. Deep chop marks occur near a recent break on the midshaft and this specimen also has cut marks on the articular surface of the distal condyles which suggests toe disarticulation (Figure 5-6). However deep indeterminate pits with internal crushing and striae emanating from their center also occur on the distal anterior surface of this specimen. It is difficult to determine whether these are the result of human, Carnivoran or Crocodile activity. Figure 5-7 shows a size bovid posterior distal metapodial fragment with cut marks related to severing the posterior tendon bundle proximal of the phalanges. In contrast to tendon removal, skinning cut marks around the distal metapodial shaft typically occur on the medial or lateral faces. These regions are not covered by thick tendon so once the skinning slice severs the hide, bone contact is likely. Specimen 724 (originally from GaJi 14B) is a size 3 mammal gonial angle fragment that has cut marks on its medial and lateral faces. These marks suggest defleshing of the masseter muscle on the lateral surface and cut marks on the medial aspect may indicate tongue removal.

Butchered size 4 Mammals bones include every bone in the appendicular skeleton excluding the carpals and tarsals. Limb girdles and upper and intermediate limb elements and ribs bear evidence of defleshing. Metapodials indicate tendon removal prior to defleshing and a size 3/4 hippo proximal phalanx has cut marks that can be interpreted as either defleshing or foot disarticulation evidence (Figure 5-8).

The largest size 5 specimen, a left ilium blade fragment belongs to an unidentified mammal and reflects defleshing.
Butchery stage analysis

Figure 5-9 shows the count of butchered NISP and MNE at GaJi 14 grouped into small and large size class categories. The single small animal specimen is the size 2 mandible described above. According to the consumption sequence, head flesh is consumed after limb flesh but before limb bone marrow. The large animal category shows butchered specimens in each stage of consumption indicating that hominins acquired carcasses early in the consumption sequence. Table 5-6 which compares butchered NISP and MNE across every size classes indicates that hominins acquired high-ranked, meaty carcass parts from even size 4 and 5 animals. Carcass parts with less abundant flesh, like the ribcage and head were also butchered. Late access butchery actions are also represented in GaJi 14, but as discussed above, it is not possible to conclusively determine whether early and late sequence butchery actions occurred on the same animal, or on elements that derive from different individual from of the same taxon. Regardless, this suggests that hominins were consumers of within bone resources and in competition with carnivorous scavengers over access to these resources.

Examining the MNE counts in each stage of carcass consumption indicates that element fragmentation has a relatively minor influence on the interpretation of hominin butchery. When butchered specimens are collapsed into a MNE unit, the count of ribs is reduced, and this depresses the number of elements in the middle butchery stage. However, most long bone elements are represented by a single specimen, so the relationship of early and late element counts matches the count based on NISP.
Elbow cluster analysis

Table 5-7 shows the attributes for each cluster and their diagnosis to defleshing or disarticulation butchery actions. Specimen 101a from GaJi 14 is a medial DNEF portion of the right humerus of a size 3/4 ungulate that has 2 clusters of cut marks and displays green fracture edges. The first cluster has many short obliquely angled cut marks in a dense cluster with relatively little deviation of angular orientation (Figure 5-10). The abundance of cut marks in this cluster and its location away from the joint surface suggest that it represents defleshing. The second cluster has three long cut marks that intersect and have a more scattered orientation suggesting defleshing. The anatomical location on the anterior aspect of the medial face of the humeral DNEF suggests defleshing the muscles that move the elbow joint including severing the biceps brachii and medial head of the triceps brachii and filleting the cleidobrachialis and coracobrachialis muscles.

Specimen 1064 from GaJi 14 is a left olecranon process of a size 3a bovid that bears cut mark clusters on the anterior, medial, lateral, posterior and superior faces. A cluster of three short, relatively parallel cut marks occur on the anterior aspect of the medial face of the olecranon process, superior to the semi-lunar notch (Figure 5-11). The small number of marks in this cluster fits best with the experimental defleshing sample, but all other attributes fall within the overlapping samples that represent both disarticulation and defleshing. Therefore, it is concluded that this sample represents defleshing the triceps brachii from its origin on the olecranon process. The second cluster contains a single cluster on the medial aspect of the superior portion of the olecranon’s
epiphysis reflects defleshing because of the cut mark count and due to its skeletal location which is completely covered by the robust tendinous termination of the triceps brachii muscle. Another dense cluster of 17 relatively long cut marks in a small area with minimal deviation of length or cut mark angle occurs on the medial face of the olecranon superior to the semi-lunar notch. In experimental cow trials, disarticulation never marked this portion of the olecranon, and in the goat sample, when disarticulation clusters occurred on the medial face, they typically had small numbers of short cut marks with minimal deviation in cut mark length or angle. This cluster is interpreted as evidence of defleshing the triceps brachii muscle. A singleton cluster on the medial aspect of the posterior spine is interpreted as evidence of defleshing the flexor carpi ulnaris muscle which primarily because of its short length, which on the posterior olecranon matches best with the experimental defleshing sample. Another cluster of five cut marks on the posterior olecranon are also interpreted as defleshing the deep digital flexor or extensor carpi ulnaris muscles because all of its attributes except for a relatively low standard deviation of cut mark angle match the experimental defleshing sample. The final cluster on this specimen contains two short cut marks on the lateral face of the olecranon in close proximity to the semi-lunar notch. Disarticulation never marked this portion in the experimental cow sample and created very few clusters in goats. All attributes of this specimen do not match well with the experimental goat values, but based on anatomical location these marks probably come from defleshing the triceps brachii attachment versus disarticulating the humerus and radioulna, which would involve severing the lateral collateral ligament at its insertion further inferior on this specimen near the inferior aspect of the semi-lunar notch and the lateral coracoid process of the ulna.
In summary, these elbow specimens, (especially the olecranon process where disarticulation and defleshing marks commonly co-occur), indicate that hominins had access to upper limb flesh, and were not forced to scavenge defleshed limb bones which were only disarticulated prior to marrow consumption.

Taken together these analytical techniques present multiple lines of evidence to interpret the carcass processing behavior of hominins at GaJi 14. In general, this site contains evidence of hominins’ early access to carcass resources the included medium and large size ungulates, and fish. Butchery of marginal carcass parts is also indicated by hammerstone fragmentation of long bones and metapodial shaft tendon removal, which is a prerequisite for fragmentation. However, these late stage actions are less common, but again this interpretation is not completely secure since it is impossible to confirm whether different specimens truly belong to the same element or individual, but elbow cluster analysis does not find evidence of disarticulation, a late stage butchery action. Carnivore tooth marks are rare on MSHs and limb bone ends are uncommon, suggesting that evidence of disarticulation may be depressed in this assemblage. On the other hand, this lack of evidence also implies that scavengers removed epiphyseal fragments as opposed to chewing them on-site, suggesting that hominins were the dominant carcass consumer at this point on the landscape.

**FwJj 14A**

*Individual specimen analysis*
The butchered assemblage at FwJj 14A contains mostly size 3 skeletal elements, but it includes a range of sizes including a size 1 mammal femur and a cervical vertebrae of a size 5 hippo (Table 5-3). Tooth-marked specimens are relatively rare. Four small specimens whose size makes them difficult to identify, including two size 2 bones and one size 3 and one size 4 mammal long bone midshaft bear traces of carnivore activity, and only one specimen preserves traces of butchery and carnivore consumption. Like the other assemblages, long bones are typically represented by shaft fragments, not epiphyses.

Evidence of defleshing exists on every size class, and the smallest mammal represented by a size 1 right femoral PNEF has evidence of defleshing and fragmentation (Figure 5-12). Defleshing of highly ranked limb girdles and upper limb elements is common in size 2 animals. Specimen 668, a size 2 mammal humeral MSH specimen preserves evidence of both defleshing and fragmentation suggesting complete consumption of carcass resources (Figure 5-13). Size 3 specimens include meaty carcass portions and elements with relatively little flesh and include specimens from all appendicular and axial skeletal groups. Specimen 1024-97 is a left tibia PNEF of a size 3 bovid that has cut marks and carnivore tooth marks (Figure 5-14). The sequence of hominin and carnivore can be determined because although, cut marks are not overlying tooth marks, both traces occur in the same region. Obviously, hominins could not butcher flesh that was missing. But these tooth marks are more likely a result of carnivore fragmentation. A tooth pit and score occur near a fracture edge with a relatively deep and narrow notch in cortical view, which is most likely a tooth notch created when a carnivore broke this bone.
Head disarticulation is also suggested by cut marks on an inferior occipital specimen from a size 3 bovid (catalog # 1203a (Figure 5-15). This butchery action may represent defleshing of marginal flesh scraps, but most likely is involved in exposing the base of the cranial to fragment it in order to access the brain. Large animals are represented by few limb bone specimens. Only a size 4 hippo humeral DNEF suggests access to large amounts of limb flesh, and size 4 mammal rib fragments and two cervical vertebrae, from a size 4 and size 5 hippo comprise the rest of the large animal sample.

Butchery stage analysis

The butchery actions reconstructed at FwJj 14A suggest that hominins enjoyed early access to both large and small carcasses as evidenced by specimens that represent consumption of limb flesh (Figure 5-16, Table 5-8). But, evidence of middle and late stage butchery actions like marginal flesh consumption, disarticulation and fragmentation are relatively more common compared to early access defleshing in the large animal sample. Counts of butchered axial specimens suggest that hominins were also exploiting the less abundant flesh on ribs, vertebrae and head parts to a greater extent in large animals. Likewise, late stage butchery evidence like fragmentation and metapodial preparation suggests that in large animals, marrow was an important resource. Bone breakage is not significantly skewing these interpretations since the relative pattern of early, middle and late access butchery actions does not change when NISP and MNE are compared. However, collapsing individual specimens into a MNE unit in this assemblage highlights an analytical concern. The tibia specimen that bears traces of hominin
defleshing followed by carnivore fragmentation for marrow is grouped with two other size 3 bovid left tibia shaft fragments into a single MNE unit. These other specimens only have evidence of hammerstone percussion and therefore suggest, late stage access to marrow. When all three specimens are collapsed into the same MNE unit, their distinct behavioral interpretations of early and late access are conflated. There is no way to determine whether these specimens belong to a single element; if they clearly did not, they would not be included in the same MNE unit, but it is important to keep in mind that any analytical technique that aggregates specimens risks mixing potentially diverse behavioral interpretations. In this example, on the NISP scale we count one tibial specimen representing early stage butchery (defleshing) and two tibial specimens representing late stage butchery actions (fragmentation), but on the MNE scale we count on tibia that represents early access and complete consumption (defleshing followed by fragmentation).

Elbow cluster analysis

Elbow specimens include humeri of two size 3 mammals and a size 5 hippo and a proximal ulnar spine from a size 3 bovid. Specimen 418 is a near-epiphysis shaft portion (and probable DNEF) of a size 3 Mammal with one cluster containing two long cut mark which are almost equal in length. The anatomical location of this cluster could not be identified on the specimen, so experimental cluster attributes for the entire DNEF portion were used for comparison. These cluster attributes suggest defleshing of the humeral DNEF.
Specimen 1022-97 is a posterio-lateral humeral DNEF fragment of a size 3 Mammal that has a cluster of six short cut marks in close proximity with minimal dispersion of length and angular orientation (Figure 5-17). The number of marks in this cluster and its area best match defleshing the lateral humerus, but the short median cut mark length, and standard deviation of mark length and angle are similar to defleshing and disarticulation experimental samples. It is possible that this cluster of cut marks represents disarticulation slices near the superior portion of the olecranon process and olecranon fossa of the humerus, but its superior location on the humeral distal shaft more likely represents severing the lateral and long heads of the triceps brachii muscle.

Specimen 6073 is a left proximal ulnar shaft of a side 3 bovid which contains a singleton cluster on the posterior border. Its length fist best with the experimental defleshing sample, but singleton clusters were only observed on the posterior spine during experimental disarticulation. It is difficult to determine which action created this mark but the recent break on this specimen and the poor surface preservation of the cortical surface may obscure additional cut mark clusters that could provide further contextual evidence for a butchery interpretation.

Specimen 103 is a size 4 hippo left humeral DNEF. This specimen is slightly weathered (WS 1) on parts, but has cut marks on pristine WS 0 bone and both green and recent fractures, indicating that additional marks may be obscured or missing (Figure 5-18). Likewise, the posterior portion and distal epiphysis are missing, limiting the visibility of potential disarticulation marks. However cluster attributes indicate that some butchery marks probably come from disarticulating the radioulna from the humerus. The first cluster on the anterior-medial face of the DNEF has only three cut marks in a small
area, which are relatively similar in length, and another cluster of two short cut marks on the medial face most closely resemble the cluster attributes of disarticulation in the experimental sample. And their anatomical location suggests severing the *extensor carpi radialis* and *cleidobrachialis* muscles which overlie the anterior and medial portions of the joint capsule. Two additional clusters on the medial face of the DNEF contain 12 and 14 cut marks that are typically long and cover a large area. These cluster attributes represent defleshing and the anatomical location reflects severing the *biceps brachii* and medial head of the *triceps brachii* and filleting the *cleidobrachialis* and *coracobrachialis* muscles. Defleshing these muscles is also supported by the presence of a scrape mark on the medial face of this specimen.

In summary, these elbow specimens indicate defleshing, and in the case of the hippo humerus, early stage defleshing of muscle was followed by disarticulation possibly to allow for fragmentation in a complete consumption strategy.

When all interpretations are considered, it is clear that hominins were not restricted to a late-access scavenging mode of foraging for carcass resources since they accessed flesh from large animals. Further, despite the lack of percussion and slicing traces on the same specimen, the interpretation of defleshing and disarticulation marks on a hippo humerus suggests that once meat was butchered from a part of the carcass, bones were prepared for fragmentation. However, is possible that scavengable flesh scraps may be more common on large animals, but whether hominins had early or intermediate access to flesh, they were not restricted to the late stage carcass resources and practiced a strategy of complete consumption of flesh and marow.
Individual specimen analysis

This assemblage does not include butchered bones of large animals (size class 4+) like the other sites, but is comprised primarily by size 3 specimens (Table 5-4). No carnivore tooth marks occur in this assemblage, and long bone ends are uncommon.

A right humeral midshaft of a *Cercopithecus* sp. monkey has evidence of defleshing (specimen 5233). This is interesting because this hominin butchery evidence is usually not documented on small, arboreal prey items. Butchery marks that represent defleshing only occur on one size 2 specimen, a bovid radial MSH fragment. A suid carpal (specimen 3055) and metacarpal (specimen 5220) from two different size 2 limbs have cut marks that indicate either skinning or foot disarticulation and preparation for fragmentation. Tendon removal is suggested by the cut marks on the medial aspect of the PNEF region of the left third metacarpal of a size 2b suid (Figure 5-19). Three size 3 mammal hyoid bones bear cut mark in the assemblage (specimens 3214, 5222, 3097, Figure 5-20). These marks are attributed to tongue removal since sagittal and transverse slices along the inferior and medial aspect of the horizontal ramus of the mandible are necessary to sever the base of the tongue from its bony attachment, and these slices overlie the shafts of the hyoid.

In larger animals, defleshing of limb girdles, upper, and intermediate limbs and axial specimens exists along with fragmentation traces on an upper, intermediate and lower limb bones, and cut marks suggesting metapodial tendon removal of prior to
fragmentation. Both tendon removal and toe disarticulation are interpreted from the cut marks on a size 3 suid fourth metatarsal (specimen 3132, Figure 5-21). Two size 3 bovid mandibular specimens occur: one has defleshing cut marks on the lingual and medial surfaces, which probably results form tongue removal (specimen 5097, not photographed), one has cut marks on the inferior surface of the mandibular symphysis which represent skinning (specimen 5214, Figure 5-22). Another size 3+ mammal cranial specimen has cut marks around the braincase that represent skinning.

Evidence of multiple butchery actions occurs on a size 3 radius and humerus. These indicate early access and complete consumption and are discussed in detail in the analysis of elbow specimens. A size 3 bovid tibial MSH also preserved evidence of defleshing and fragmentation.

*Butchery stage analysis*

When butchered specimens are tallied, evidence of processing large carcasses is much more common in FwJj 14B, (Figure 5-23 and Table 5-9). In size 1 and 2 animals, only two specimens represent early access to flesh, one rib specimen represents marginal flesh consumption, and two specimens suggest preparation for fragmentation. The large size class only includes size 3 animals, and here early access defleshing is more commonly represented by butchered specimens than late access butchery actions. On the NISP scale middle stage actions like rib defleshing and tongue removal are the most abundant traces of butchery, but when rib specimens are collapsed into MNE groups, only two rib elements are included in the count of middle stage butchery actions.
Although the true number of ribs in the assemblage is unknown, the process of fragmentation that reduced these elements into less identifiable rib shaft fragments of size 3 mammals influences the relative proportions of different butchery stage counts. In contrast, fragmentation did not impact limb elements as severely, and their contribution to early and late stage butchery trace counts are not substantially altered. In this assemblage both early and late access butchery actions are preserved and as indicated above certain specimens preserve traces of defleshing and fragmentation.

Elbow cluster analysis

Specimen 5128 is a right size 2b Radial PEPI and PNEF fragment with recent breaks, making the determination of green fracture impossible (Figure 5-24). The first cluster of four cut marks occur on the anterior-lateral corner on the epiphyseal border of the fovea capitis. Comparing this specimen to both goat and cow experimental clusters indicates that the number of cut marks at this anatomical location fits better with disarticulation clusters. This is supported by the anatomical location, which is likely to be incised with a cluster of cut marks when the joint capsule and lateral collateral ligament are severed. The second cluster of two cut marks is on the anterior non-epiphyseal face of the fovea capitis, and fits with defleshing cluster attributes due to the small number of short marks and their nearly parallel angular orientation. However, the anatomical location of these marks fits best with disarticulation when severing the joint capsule. The third cluster contains two marks and occurs on the anterior-medial face of the radial PNEF. In the experimental sample, disarticulation did not create cut marks on the radial
PNEF in cows, so the goat sample is examined since both actions cut marked the anterior PNEF. The small number of marks is similar to both disarticulation and defleshing, but the small area and short cut mark length is more similar to the disarticulation sample. The other cluster attributes are far below the experimentally demonstrated values and are considered indeterminate. Taken together this specimen represents disarticulation of the elbow joint and possible defleshing of the lateral proximal shaft in the area of the brachialis, common digital extensor, extensor carpi radialis and lateral digital extensor muscles.

Specimen 6090a is a right proximal radius PEPI and PENF fragment of a size 3 bovid (Figure 5-25). The first cluster has two cut marks on the posterior-lateral corner of the epiphyseal portion of the fovea capitis. This anatomical location was not cut-marked in the experimental butchery sample, but the small number of marks in this archaeological cluster fits best with disarticulation. Likewise, cut marks directly on the epiphyseal bone are indicative of cortical contact while severing the joint capsule and the lateral collateral ligament. The second cluster occurs on the lateral face of the PNEF and contains 11 cut marks. The large number of marks, large cluster area and standard deviation of cut mark angle fit with defleshing the common digital extensor, extensor carpi radialis and lateral digital extensor muscles. The third cluster contains seven cut marks on the anterior face of the PNEF. Its area, median cut mark length, and angle standard deviation are similar to the experimental defleshing cluster values. This cluster probably represents filleting the extensor carpi radialis and brachialis muscles.

Specimen 3090 is a left humeral DNEF fragment from a size 3 Bovid which displays green fracture and a cluster of 6 cut marks proximal to the lateral epicondyle on
the lateral face (Figure 5-26). The number of marks, and their relatively uniform length in
the cluster suggest defleshing, but other cluster attributes can be attributed to either
defleshing or disarticulation. The skeletal location of the cluster seems too far anterior
and superior to result unequivocally from disarticulating the humerus and radioulna.
More likely this cluster results from severing the lateral head of the *triceps brachii* and
*brachialis* muscles.

Specimen 5099 is a right lateral and posterior DNEF fragment from a size 3 bovid
with clusters of cut marks, percussion striae and green fracture (Figure 5-27). The lateral
face of this specimen has cut marks that cross the green fracture edge and a percussion
mark which indicates hammerstone fragmentation. The first cluster has two cut marks in
a relatively small area and fits with both disarticulation and defleshing cluster attributes
for the lateral humeral DNEF. However, the anatomical location indicates that these
marks originate from filleting the long head of the *triceps brachii* muscle. Likewise the
second cluster on the lateral face contains 19 short cut marks adjacent to the lateral
epicondyle best matches the cluster attributes of defleshing, and probably represents
filleting this upper arm flexor which overlies the lateral DNEF. However, another cluster
of two cut marks occurs closer to the anterior-lateral corner and inferior to the other
marks. Its small cluster area fits best with the disarticulation sample of experimental
clusters, and its other attributes are difficult to diagnose to either butchery action. Its
anatomical location reflects severing muscles and connective tissue during joint
disarticulation including the *common digital extensor* muscle and *extensor carpi radialis*.
Two additional clusters of cut marks occur on the posterior faces of both the medial and
lateral epicondyles. One large cluster and one small cluster both match best with
defleshing cluster attributes, primarily because disarticulation never cut-marked the posterior DNEF in any experimental trial, and their long marks. The anatomical location of these clusters also reflects filleting the overlying long head of the triceps brachii muscle.

Specimen 5067 is a right proximal ulna of a size 3 bovid. Its first cluster contains three relatively long cut marks on the anterior crest of the olecranon process (Figure 5-28). The cut marks count and cluster area fit with both defleshing and disarticulation samples but these marks’ great length and high deviation of length coupled with low deviation of angular orientation all point toward defleshing. Further, the anatomical location of this cluster suggests severing the triceps brachii insertion. An additional cluster of three marks on the posterior olecranon border was mistakenly not photographed for analysis, but could represent either butchery action based on cut mark count. The final cluster contains a single, relatively short cut mark on the posterior border of the proximal ulnar spine. Its characteristics fit best with defleshing and this cluster probably represents severing the extensor carpi ulnaris or deep digital flexor muscles.

Specimen 5117 is a size 3 bovid left proximal ulnar spine that includes the region inferior to the proximal interosseous space where the ulnar shaft is fused to the posterior radius (Figure 5-29). Since the ligaments articulating the humerus and radioulna terminate superior to the area preserved in this specimen, only medial face where the pronator teres muscle attaches has potential to preserve traces of disarticulation. However, this region did was not cut marked in the experimental cow or goat sample. The first archaeological cluster occurs on the posterior-medial face and contains three relatively long cut marks in a small area. All cluster attributes match with defleshing and
its anatomical location is too far inferior to reflect severing the *pronator teres* attachment during elbow disarticulation. The second cluster contains five short cut marks in large area on the posterior border and matches the experimental defleshing sample in each attribute. Its anatomical location suggests defleshing the *deep digital flexor* muscle. The final cluster contains two very long cut marks that are oriented longitudinally with respect to the ulnar shaft. The attributes of this cluster match the experimental defleshing sample and probably represent defleshing the *deep digital flexor* muscle.

In summary, the size 2 bovid radius has cut marks that most likely originate from disarticulation but many cluster attributes could not be compared. The size 3 elbow specimens have butchery traces from the entire sequence of actions, defleshing, disarticulation and fragmentation, in fact these all co-occur on specimen 5099.

These multiple interpretations of the butchered bone from FwJj 14B indicates that all stages of hominin carcass consumption are recorded in this assemblage and that these diverse traces of butchery may represent complete consumption of individual carcass parts.

**Discussion**

*Paleoecological interpretation of Okote Member butchery traces*

Overall, GaJi 14, FwJj 14A and B share some general paleogeographic characteristics. They all occur near water sources on ancient landscapes amidst the savannah mosaic of ecotones including riparian woodland, woody and bush grassland
(Pobiner, *et al.*, 2008). However, it is important to note that these sites are not exactly contemporaneous, but all were deposited around 1.5 Ma within less than 40 Ka of each other, therefore interpretations of hominin paleoecology are not meant to suggest that a single hominin group created all three assemblages while foraging across a paleolandscape. Rather, paleogeographic differences between the Ileret and the Koobi Fora Ridge predict that foraging hominins would encounter different environmental affordances in these areas (Blumenschine and Peters, 1998). This chapter interprets the paleoecological context of hominins’ stone-tool assisted carnivorous foraging behavior with a careful study of butchery trace fossils that identify distinct modes of carcass consumption.

The GaJi 14 assemblage was deposited in a low energy channel sands that drained into a shallow, lake shore environment on the present-day Koobi Fora Ridge, suggesting a marshy habitat with possibility of some riparian tree cover. Of all three assemblages, it contains the largest animals, and butchered specimens are mainly from size 3 and 4 animals. Butchery traces indicate that large packages of carcass resources were consumed, either as flesh from highly ranked skeletal regions or from the bone marrow of large animal limb bones. Evidence of defleshing skeletal regions with marginal flesh yields like the ribs and head are relatively uncommon. Some of the specimens that are fragmented have chop-like marks with deep v-shapes and internal striations. These marks do not display typical bisected pit morphology and occur near fracture edges, which eliminates crocodile consumption as a casual process. It seems likely that these elements were fragmented with sharp-edge core tools. Percussion pits from core tool have not been studied in detail, and further actualistic research should easily be able to define diagnostic
criteria to differentiate percussion with hammerstones versus core tools. Two fish spines have cut marks suggesting that flesh was consumed from aquatic sources as well.

An interesting specimen at GaJi 14 bears traces of hominin butchery and both crocodile and terrestrial carnivore tooth marking, but otherwise only one other tooth marked specimen, which does not preserve butchery traces occurs in the assemblage. This suggests that the lake shore setting was a habitat where a variety of carnivores consumed carcass resources, including hominins who enjoyed early access to carcass resources, crocodiles, and bone scavengers who probably removed limb fragments with epiphyses for off-site consumption. The presence of trees or other vegetation probably provided shade for hominins at a site where ungulates drank, natural deaths of water-loving species occurred and other carnivores may have hunted.

The closest source of stone tool raw materials occur between 15 and 20 km away in the eastern basin margin, and the lack of stone tools in the excavated assemblage and the possible core tool fragmentation supports the idea that tools were curated and infrequently discarded (Bunn, 1981, 1994).

In the Ileret region, FwJj 14A occurs in a distal floodplain context, suggesting that if this channel was seasonally active, water was an impermanent landscape feature. This describes a different affordance structure at this site. Perhaps less vegetation occurred near the site. Stone tool resources are not locally abundant; they occur only 5 km from the site, but stone tool curation was still practiced since no tools or flaking debris was recovered in the excavation. The butchered specimens suggest a different paleoecological role for hominins at FwJj 14A. This assemblage contains a higher proportion of middle-stage butchery actions compared to other sites, which indicate that skeletal segments
containing marginal flesh scraps like the ribs and cranium were routinely consumed. Evidence of primary and late stage carcass access indicated by defleshing of meaty limb elements and fragmentation traces still occur, but this assemblage has the greatest proportion of butchery traces on smaller ungulates. Also this assemblage has the most specimens with carnivore tooth marks, and one tibial shaft shows that on-site carnivore consumption followed hominin defleshing. Together the fact that hominins were consuming smaller carcasses, more marginal flesh and scavenging carnivores were active on-site suggest that FwJj 14A was an area on the landscape where hominin-carnivore competition over carcass resources was more intense.

The geological context of FwJj 14B suggests that butchery occurred on the bank of a broad, shallow stream, in a riparian woodland setting. Compared to 14A, the butchered assemblage is dominated by size 3 animals, and no evidence of carnivore tooth marking was found. A butchered size 1 *Cercopithecus* monkey humerus supports the gallery forest habitat reconstruction. Butchery traces suggest that carcass consumption was centered around early access to the flesh of large mammals but late access may also be indicated by marks that show metapodials were prepared for fragmentation. However, complete consumption by hominins is indicated by specimens that have cut marks representing both early and late access. A humerus and tibia show that hominins defleshed and then fragmented these long bones, and a fragmentary proximal radius does not have direct evidence of percussion, but has defleshing and disarticulation cut marks. If this relatively closed riparian habitat had paleoecological dynamics similar to those observed in modern gallery forest settings, reduced competition for carcasses flesh during primary carnivore consumption may have given hominins greater chances of successful
confrontational scavenging (Blumenschine et al., 1994). This idea is supported by the butchery traces in for size 3 animals.

It is difficult to determine whether these assemblages represent butchery of animals found in the respective location or whether butchered specimens reflect carcass access in a different habitat and transport to the site for butchery and consumption. Home base/central place sites (Isaac, 1983) are difficult to distinguish from repeatedly used butchery sites in general because of the equifinality in which density mediated destruction mimics hominins’ selective transport of highly-ranked limb elements. It is not possible to determine whether marginal carcass resources like cranial and axial elements were left at the kill site or whether they were deleted from the assemblage by scavengers. Likewise, detecting allochthonous fauna in an assemblage is confused by the identification of these animals mainly by dental specimens, which are not common in the butchered assemblage. So the overall taxonomic list is somewhat distorted by the natural background fauna that occurred on the ancient landscape (Behrensmeyer, 1983).

Regardless, it seems logical to conclude that hominins who knew the locations of stone raw material sources and curated stone tools over the landscape for up to 20 km had some idea of what resources to expect in certain habitats. Whether these resources (a fresh kill guarded by a single carnivore for example) were encountered and the specific carcass condition were the paleoecological contingencies that constrained hominins’ foraging behavior. I suggest that during the Okote Member Homo erectus was an opportunistic generalist carcass consumer that would fully consume carcass resources when they were encountered. Indeed, some of the butchered specimens show evidence of this behavior. Further, while large bodied carnivores move over large home ranges and
differentially engage in social hunting, contemporary observations suggest regularities in carnivore behavioral ecology and how these parameters affect carcass consumption. Specifically, as the number of competing carnivores increases, the availability of carcass resources available to hominins is reduced, and competition is significantly greater in open habitats (Blumenschine, 1986, 1989, Blumenschine et al., 1994). If this was also the case during Okote Member times which had a similar Carnivoran guild structure to the modern east African guild (except for the presence of H. erectus), foraging hominins would soon learn that carcass resources were more abundant in relatively closed, wooded habitats. Transporting carcass parts, including those of large animals to landscape facets where butchery took place was also part of Homo erectus’ behavioral repertoire. In addition, it seems that Homo erectus was successful at keeping scavenging carnivores at bay, since evidence of hyenas’ on-site bone crunching is almost absent in the Okote Member, indicating that these zooarchaeological assemblages may represent an early example of long-term ecological control over landscape localities.

Pobiner et al.’s (2008) interpretation of Okote paleoecology generally matches mine, but is based on a more traditional interpretive strategy that does not explicitly interpret butcher actions and use them to evaluate the order in which hominins were active in the sequence of carcass consumers. Another foraging strategy proposed by Bunn (1994) investigates other cut marked surface finds and assemblages of bone from the Koobi Fora ridges and Ileret. Bunn (1994) initially proposed the tool curation idea, which is supported by the data presented here, especially the evidence which is suggestive of limb bone fragmentation with core tools at GaJi 14. Bunn characterizes Okote Member archaeological assemblages on the Karari Ridge (mainly FxJj 50), which include
abundant stone tools made from locally available cobbles and butchered bone as home base/central place localities where carcass parts were routinely transported for complete consumption. Unfortunately, as Bunn acknowledges the poor preservation of bone in Karari sites affects the description of butchery marks in these assemblages. In contrast, based largely on a complete pygmy hippo femur with evidence of defleshing, Bunn suggests that hominins foraging across the Koobi Fora Ridge and Ileret areas practiced an “ape-like, feed-as-you-go” strategy where flesh was removed from large animals, but complete consumption, specifically fragmentation was rare (1994:262).

The results of my interpretation are based on additional archaeological assemblages from the Koobi Fora Ridge and Ileret which greatly expanded the dataset of butchery evidence in these habitats, but show that these conclusions cannot be supported. Foraging hominins may have briefly occupied these localities, but they were repeatedly visited since many individuals are represented. Both large and small animals were consumed on the sites and evidence for complete consumption is present on many elements, including hippo bones that comprise the largest fraction of the assemblage.

Methodological considerations

Previous studies of Okote member butchery evidence do not examine cut-marked specimens as closely as this study. Bunn lists butchered specimens according to taxon, size class and skeletal portion, but describes butchery traces in a general way as “multiple cuts, transverse, lateral surface” (1994: Table 1). The bone surface modifications on some
specimens are interpreted to represent butchery actions such as defleshing or fragmentation, but this is not applied to the entire sample of butchered specimens.

Pobiner (2007, Pobiner et al., 2008) presents a much more careful consideration of the butchery traces in GaJi 14 and FwJj 14A and B. However her analyses follow traditional strategies of interpretation that examine the proportion of butchery traces in the total assemblage. While this scale of analysis is important for documenting the biases that must be considered when interpreting specimens of different elements, it is affected by the degree of fragmentation in an assemblage and equifinality over the agents and processes that created the assemblage’s skeletal element and portion profile (see the concluding chapter for a complete discussion).

All of these interpretive problems are introduced by the structure of fragmentary zooarchaeological evidence. Butchered and broken specimens of the same individual or skeletal element become disassociated from one another, and certain portions are deleted, making the identification of different fragments of one animal a matter of inference. Along with the difficulty of determining which bones belong to one organism, comes the possibility similar specimens with respect to size, taxon element etc. are analytically identical remains of different individuals. Inferring butchery behavior from this sort of evidence is a complex task where interpretive uncertainty should be carefully considered.

To step around these analytical difficulties, I chose to examine the butchered sub-assemblage in detail. While this method may underestimate the number of elements or individuals in the total assemblage, it does not encounter the difficulty of assigning behavioral meaning to specimens that do not preserve bone surface traces of their taphonomic history.
Interpreting the butchery actions on individual bone specimens was based on actualistic observations of the butchery process, and while taphonomic process like carnivore scavenging in addition to hominin behavior affected the abundance of these specimens, the goal of this analysis was to document the presence or absence of hominins’ early, middle and late access butchery traces. Transforming specimens into MNE estimates gave a simple measurement of whether fragmentation severely distorted the relative abundance of these traces. However this aggregation of specimens was shown to conflate distinct behavior interpretations on different specimens, and establishing whether this is correct is never truly possible when different fragments of the same MNE unit do not refit. This difficulty is increasingly recognized by zooarchaeologists who try to make sense of fragmentary assemblages (Greyson and Frey, 2004, Lyman, 1994, 2008, Marean et al., 2004, Outram, 2004). This conflation of behavioral interpretation is the reason why the analysis of butchery stage evidence does not include an MNI or MAU scale. When examining this assemblage which has many common elements, it is difficult to conclude whether many of the size 3 bovid right limbs at GaJi 14 for example truly come from the same individual. I suggest that assigning specimens to aggregate unit which describe the minimum number of elements or individuals follows a rigid interpretive formula which can be counterproductive when it muddles behavioral interpretation in sets of specimens. These analytical units were designed to estimate numbers of bones or animals, not to accurately describe taphonomic traces on sets of specimens.

For this reason, the elbow cluster analysis is preferred because it investigates traces of early and late hominin butchery actions on the same specimen. While it does not
formulate an interpretation by examining the entire assemblage, it identifies a source of evidence which is least likely to be affected by the uncertainty of archaeological inference.
The Surgei Plateau is the volcanic highland area to the east of the lake and the Kokoi uplift, which did not exist during Okote Member times is located near the Karari Ridge.
Table 5-1: Taxonomic list for Okote member assemblages (reprinted from Pobiner et al., 2008).

<table>
<thead>
<tr>
<th>Class</th>
<th>Order</th>
<th>Family</th>
<th>Genus</th>
<th>Species</th>
<th>MN1</th>
<th>NSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reptilia</td>
<td>Crocodylia</td>
<td>Crocodyliidae</td>
<td>Crocodylus</td>
<td>sp.</td>
<td>25</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Elapodesmus</td>
<td>braunoi</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Eupodectes</td>
<td></td>
<td>24</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Crocodylia</td>
<td>Crocodyliidae</td>
<td>Crocodylus</td>
<td>sp.</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Squamata</td>
<td>Squamata</td>
<td>Varanus</td>
<td>varanoides</td>
<td>71</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Varanus</td>
<td>sp.</td>
<td>151</td>
<td>75</td>
</tr>
<tr>
<td>Ornithischia</td>
<td>Saurornithes</td>
<td>Saurornithidae</td>
<td>Varanus</td>
<td>sp.</td>
<td>151</td>
<td>75</td>
</tr>
<tr>
<td>Mammalia</td>
<td>Archaeocyonida</td>
<td>Bovidae</td>
<td>Varanus</td>
<td>varanoides</td>
<td>71</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Varanus</td>
<td>sp.</td>
<td>151</td>
<td>75</td>
</tr>
</tbody>
</table>

*MN1 (minimum number of individuals) is listed for mammals only at or below the family level, except Bovidae. Body size classes, following Bunn (1982), are listed for mammals in the superscript text next to the MN1. Juvenile individuals are designated with a superscript j, also associated with the MN; all other individuals are adults. For MN1 and NSP, the values for PwJ44A are on the left, those for PwJ44B are in the center, and those for Gah14 are on the right. MN1 number for Gah14 reported in the text includes one Hipposideros, one large Suidae, and the two Equidae, as those individuals could be the same as those identified as *Hippopotamus protosprangius*, *Kobus* incertae affiliation, and *Equus* sp. Five Equidae specimens, all fragmentary teeth, are likely *Equus* robustus based on measured age estimates (Harari, 1963). The species designation of *Theropithecus oswaldi* is made based on measured age estimates, as is the only species of *Theropithecus* found during this time interval in the Turkana Basin (Lee, 1993). Hipposideros specimens not positively identified as *Hippopotamus protosprangius* are included in Hipposideros NSP, but are included in the species MN1. NSP for Bovidae specimens does not include those specimens identified above the family level.
Table 5-2: Butchered specimens at GaJi 14.

<table>
<thead>
<tr>
<th>Size</th>
<th>Taxon</th>
<th>Side</th>
<th>Element</th>
<th>Portion</th>
<th>Location</th>
<th>Marks Present</th>
<th>Agent</th>
<th>Stage</th>
<th>Action</th>
<th>Cat #</th>
<th>Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Bovidae</td>
<td>MANO</td>
<td>HRAM</td>
<td>post face</td>
<td>CM,CH,PS</td>
<td>Hominin</td>
<td>mid</td>
<td>fragmentation, defleshing</td>
<td>1025d</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>R</td>
<td>MSH</td>
<td>post face</td>
<td>SC,CM</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>1055</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>L</td>
<td>MSH</td>
<td>ant med</td>
<td>CM</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>1096</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>L</td>
<td>SCAP</td>
<td>BLADE</td>
<td>nid</td>
<td>CM,SC</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>1079-S</td>
<td>GaJi 14 A</td>
</tr>
<tr>
<td>3</td>
<td>Ungulata</td>
<td>R</td>
<td>SCIAP</td>
<td>neck</td>
<td>CM</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>1058</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>L</td>
<td>TIB</td>
<td>post face</td>
<td>CM</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>1052</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>L</td>
<td>MSH</td>
<td>post med or post lat corner</td>
<td>PS</td>
<td>Hominin</td>
<td>late</td>
<td>fragmentation (possible core tool)</td>
<td>1041</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3a</td>
<td>Bovidae</td>
<td>L</td>
<td>UMEN</td>
<td>Olecranion lat face behind s notch</td>
<td>CM</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>1064</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>R</td>
<td>FEM</td>
<td>adjacent to linea aspera</td>
<td>CM</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>1058</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>R</td>
<td>MSH</td>
<td>ant face</td>
<td>CM</td>
<td>Hominin</td>
<td>late</td>
<td>tendon removal, fragmentation</td>
<td>6</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>L</td>
<td>MSH</td>
<td>posterior face</td>
<td>CM</td>
<td>Hominin</td>
<td>late</td>
<td>defleshing, tendon removal</td>
<td>1047abc</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>L</td>
<td>DEPI</td>
<td>central ridge of lat condyle</td>
<td>CM,CH,PS</td>
<td>Hominin</td>
<td>late</td>
<td>fragmentation (with core tool), toe disarticulation</td>
<td>1007</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>R</td>
<td>MP</td>
<td>ant</td>
<td>ST,PS,CM,PS</td>
<td>Hominin</td>
<td>late</td>
<td>defleshing, tendon removal, fragmentation</td>
<td>109</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>R</td>
<td>DNEF</td>
<td>post face</td>
<td>CM</td>
<td>Hominin</td>
<td>late</td>
<td>defleshing</td>
<td>902</td>
<td>GaJi 14 B</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>R</td>
<td>MSH</td>
<td>NIF</td>
<td>PS</td>
<td>Hominin</td>
<td>late</td>
<td>fragmentation</td>
<td>1046</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>L</td>
<td>MED</td>
<td>CAL</td>
<td>Crocodile, Hominin, Carnivore</td>
<td>late</td>
<td>defleshing, prob scavenging</td>
<td>1119</td>
<td>GaJi 14 A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3b</td>
<td>Mammal</td>
<td>R</td>
<td>MANO</td>
<td>right lateral face</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing</td>
<td>1071</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>R</td>
<td>MSH</td>
<td>med and lateral face</td>
<td>CM,LS</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing, poss evasculation</td>
<td>1035</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>R</td>
<td>MSH</td>
<td>med or lateral face</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing</td>
<td>1065</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>R</td>
<td>MSH</td>
<td>ant or post face</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing</td>
<td>1033</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>R</td>
<td>MSH</td>
<td>ant or post border</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing</td>
<td>1033</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>L</td>
<td>MSH</td>
<td>med-dist edge, distal of neck</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing, possible evasculation</td>
<td>1038</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>R</td>
<td>MSH</td>
<td>med face</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>evasculation</td>
<td>1089</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>R</td>
<td>MSH</td>
<td>lateral edge of fossa</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing</td>
<td>1021</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>L</td>
<td>MSH</td>
<td>lat</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing</td>
<td>107</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>R</td>
<td>MSH</td>
<td>lat</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing</td>
<td>1085b</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3b/4</td>
<td>Mammal</td>
<td>L</td>
<td>SCAP</td>
<td>med surface</td>
<td>CM,SC</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>1026ab</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Mammal</td>
<td>R</td>
<td>MSH</td>
<td>ant or post face</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing</td>
<td>1056</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3/4</td>
<td>Ungulata</td>
<td>R</td>
<td>HUM</td>
<td>DNEF</td>
<td>med</td>
<td>CM</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>1042</td>
<td>GaJi 14 A</td>
</tr>
<tr>
<td>3/4</td>
<td>Mammal</td>
<td>R</td>
<td>ILLU</td>
<td>shaft</td>
<td>CM</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>1042</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3/4</td>
<td>Mammal</td>
<td>R</td>
<td>ILLU</td>
<td>infr edge</td>
<td>CM</td>
<td>Hominin</td>
<td>late</td>
<td>defleshing</td>
<td>931</td>
<td>GaJi 14 B</td>
<td></td>
</tr>
<tr>
<td>3/4</td>
<td>Mammal</td>
<td>R</td>
<td>MAD</td>
<td>med and lat</td>
<td>CM</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>1013</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3/4</td>
<td>Ungulata</td>
<td>L</td>
<td>TIB</td>
<td>post lat corner</td>
<td>CM</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>1019</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3/4</td>
<td>Mammal</td>
<td>L</td>
<td>LB</td>
<td>indet</td>
<td>CM,PS,ST</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing, fragmentation</td>
<td>1001</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Bovidae</td>
<td>L</td>
<td>MED</td>
<td>DNEF</td>
<td>medial face</td>
<td>CM</td>
<td>Hominin</td>
<td>late</td>
<td>defleshing</td>
<td>1064b</td>
<td>GaJi 14 A</td>
</tr>
<tr>
<td>4</td>
<td>Bovidae</td>
<td>L</td>
<td>MC</td>
<td>DNEF</td>
<td>medial face</td>
<td>CM</td>
<td>Hominin</td>
<td>late</td>
<td>defleshing</td>
<td>1036</td>
<td>GaJi 14 A</td>
</tr>
<tr>
<td>4</td>
<td>Bovidae</td>
<td>R</td>
<td>MSH</td>
<td>ant</td>
<td>CM</td>
<td>Hominin</td>
<td>indet</td>
<td>defleshing</td>
<td>543</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3/4</td>
<td>Hominidae</td>
<td>L</td>
<td>PPHH</td>
<td>ant-med or ant-lat</td>
<td>CM</td>
<td>Hominin</td>
<td>late</td>
<td>foot tendon removal or defleshing</td>
<td>7</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3/4</td>
<td>Ungulata</td>
<td>R</td>
<td>MSH</td>
<td>indet</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing, possible evasculation</td>
<td>1017</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>3/4</td>
<td>Mammal</td>
<td>R</td>
<td>MSH</td>
<td>med</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing, possible evasculation</td>
<td>510</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Mammal</td>
<td>R</td>
<td>MSH</td>
<td>shaft</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing</td>
<td>1045</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>5/6</td>
<td>Mammal</td>
<td>L</td>
<td>ILLU</td>
<td>blade</td>
<td>inferior face</td>
<td>CM,SC</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>1090</td>
<td>GaJi 14 A</td>
</tr>
<tr>
<td>nd</td>
<td>Mammal</td>
<td>R</td>
<td>MSH</td>
<td>indet</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing</td>
<td>108</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>nd</td>
<td>Mammal</td>
<td>R</td>
<td>MSH</td>
<td>lat-dist edge</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing</td>
<td>568</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>nd</td>
<td>Mammal</td>
<td>R</td>
<td>MSH</td>
<td>lat face</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing</td>
<td>1046f</td>
<td>GaJi 14 A</td>
<td></td>
</tr>
<tr>
<td>nd</td>
<td>FISH</td>
<td>R</td>
<td>spina</td>
<td>spina</td>
<td>CM</td>
<td>Hominin</td>
<td>defleshing</td>
<td>637</td>
<td>GaJi 14 A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>nd</td>
<td>FISH</td>
<td>L</td>
<td>spina</td>
<td>spina</td>
<td>CM</td>
<td>Hominin</td>
<td>defleshing</td>
<td>689</td>
<td>GaJi 14 A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>L</td>
<td>LB</td>
<td>spina</td>
<td>CM</td>
<td>Carnivore</td>
<td>defleshing</td>
<td>672</td>
<td>GaJi 14 B</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The larger of intermediate size classes was used when assigning specimens to size category. Small carcasses include size 1 and 2 specimens. Large carcasses include size 3 and larger specimens. Butchery marks include cut marks (CM), chop marks (CH), scrape marks (SC), percussion pits (PM), percussion striae (ST), isolated patches of microstriations (ST), tooth marks (TM), indeterminate striae (IS), and indeterminate pits (IP). The set of specimens included in an MNE estimate is colored either grey or white and is enclosed by a box. Cat # refers to the catalog number of this specimen in the site log.
<table>
<thead>
<tr>
<th>Size</th>
<th>Taxon</th>
<th>Element</th>
<th>Portion</th>
<th>Marks Present</th>
<th>Present Agent</th>
<th>Stage</th>
<th>Action</th>
<th>Cat #</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mammal</td>
<td>FEM</td>
<td></td>
<td></td>
<td>Hominin</td>
<td>early</td>
<td>defleshing, poss fragmentation</td>
<td>1101</td>
</tr>
<tr>
<td>2</td>
<td>Mammal</td>
<td>HUM</td>
<td>MSH</td>
<td>ST,CM,PM</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing, fragmentation</td>
<td>668</td>
</tr>
<tr>
<td>2b</td>
<td>Mammal</td>
<td>HUM</td>
<td>MSH</td>
<td>CM</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>610</td>
</tr>
<tr>
<td>2 or 3</td>
<td>Mammal</td>
<td>Innominate</td>
<td>blade</td>
<td>SC</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>9</td>
</tr>
<tr>
<td>2b</td>
<td>Mammal</td>
<td>L</td>
<td>ILUM</td>
<td>ramus</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>1014-97</td>
</tr>
<tr>
<td>2b</td>
<td>Mammal</td>
<td>L</td>
<td>ILUM</td>
<td>Horiz ramus</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>1226</td>
</tr>
<tr>
<td>2b</td>
<td>Bovidae</td>
<td>L</td>
<td>MT</td>
<td>DNEF</td>
<td>Hominin</td>
<td>late</td>
<td>disarticulation of phalanges</td>
<td>1007-97</td>
</tr>
<tr>
<td>2b</td>
<td>Bovidae</td>
<td>L</td>
<td>TIB</td>
<td>PNEF</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>112, 1125</td>
</tr>
<tr>
<td>2b</td>
<td>Mammal</td>
<td>RIB</td>
<td>MSH</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing</td>
<td>1020-97</td>
</tr>
<tr>
<td>2b</td>
<td>Mammal</td>
<td>THO</td>
<td></td>
<td></td>
<td>Hominin</td>
<td>mid</td>
<td>thoracic disarticulation</td>
<td>1028</td>
</tr>
<tr>
<td>2b/3a</td>
<td>Bovidae</td>
<td>L</td>
<td>MAND</td>
<td>Hor ram</td>
<td>Hominin</td>
<td>mid</td>
<td>skinning or defleshing??</td>
<td>1112</td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>R</td>
<td>MAND</td>
<td>Coracoid proc</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing</td>
<td>5007</td>
</tr>
<tr>
<td>2b/3a</td>
<td>Mammal</td>
<td>MAND</td>
<td>asc ram</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing or mandible disartic</td>
<td>1001-97</td>
</tr>
<tr>
<td>2b/3a</td>
<td>Mammal</td>
<td>MC</td>
<td>DNEF</td>
<td>CM</td>
<td>Hominin</td>
<td>late</td>
<td>skinning, tendon filleting</td>
<td>1003-97</td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>MP</td>
<td>DNEF</td>
<td>CM</td>
<td>Hominin</td>
<td>late</td>
<td>tendon filleting</td>
<td>1015-97</td>
</tr>
<tr>
<td>2b/3a</td>
<td>Bovidae</td>
<td>L</td>
<td>TIB</td>
<td>MSH</td>
<td>Hominin</td>
<td>late</td>
<td>fragmentation</td>
<td>1107</td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>L</td>
<td>TIB</td>
<td>MSH</td>
<td>Hominin</td>
<td>late</td>
<td>fragmentation</td>
<td>1107</td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>L</td>
<td>ULN</td>
<td>PNEF</td>
<td>Hominin</td>
<td>ined</td>
<td>defleshing or disarticulation??</td>
<td>6073</td>
</tr>
<tr>
<td>2b/3a</td>
<td>Mammal</td>
<td>ULN</td>
<td>MSH</td>
<td>CM</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>321,348</td>
</tr>
<tr>
<td>2b/3a</td>
<td>Suidae</td>
<td>R</td>
<td>ASTR</td>
<td>px condyle</td>
<td>Hominin</td>
<td>late</td>
<td>disartic of foot and separation of tarsals</td>
<td>1093</td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>L</td>
<td>FEM</td>
<td>PNEF</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>1019-97</td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>FEM</td>
<td>MSH</td>
<td>CM</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>1056</td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>FEM</td>
<td>MS</td>
<td>ST</td>
<td>Hominin</td>
<td>late</td>
<td>fragmentation</td>
<td>1397a</td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>R</td>
<td>Occip</td>
<td>inf</td>
<td>Hominin</td>
<td>late</td>
<td>head disarticulation</td>
<td>1203a</td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>R</td>
<td>PAT</td>
<td>ant non-epip</td>
<td>Hominin</td>
<td>mid</td>
<td>knee disarticulation</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>L</td>
<td>HUM</td>
<td>NEF</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>418</td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>L</td>
<td>HUM</td>
<td>DNEF</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>1022-97</td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>L</td>
<td>HUM</td>
<td>PNEF</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>2611a</td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>R</td>
<td>LUMB</td>
<td>pre-zygop</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>140</td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>L</td>
<td>LUMB</td>
<td>Neur sp</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>1170</td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>RAD</td>
<td>MSH</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing</td>
<td>1002-97</td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>RIB</td>
<td>MSH</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing intercostal</td>
<td>6063</td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>RIB</td>
<td>MSH</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing intercostal</td>
<td>6084</td>
</tr>
<tr>
<td>2b/3a</td>
<td>Mammal</td>
<td>RIB</td>
<td>neck</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing intercostal</td>
<td>1289</td>
</tr>
<tr>
<td>3a</td>
<td>Bovidae</td>
<td>R</td>
<td>TSCH</td>
<td>ramus</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>102</td>
</tr>
<tr>
<td>4</td>
<td>Hippopotamida</td>
<td>CERV</td>
<td>centrum</td>
<td>IS,CM</td>
<td>Hominin</td>
<td>mid</td>
<td>???</td>
<td>1221</td>
</tr>
<tr>
<td>4</td>
<td>Hippopotamida</td>
<td>L</td>
<td>HUM</td>
<td>DNEF</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing and disarticulation</td>
<td>103</td>
</tr>
<tr>
<td>4</td>
<td>Mammal</td>
<td>RIB</td>
<td>MSH</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing</td>
<td>431</td>
</tr>
<tr>
<td>4</td>
<td>Mammal</td>
<td>RIB</td>
<td>dist Shaft</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing or viscera removal</td>
<td>6346</td>
</tr>
<tr>
<td>4+</td>
<td>Mammal</td>
<td>RIB</td>
<td>MSH</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing</td>
<td>1210</td>
</tr>
<tr>
<td>5</td>
<td>Hippopotamida</td>
<td>CERV</td>
<td>centrum</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing, possible neck disartic</td>
<td>1012-97</td>
</tr>
<tr>
<td>2+</td>
<td>Mammal</td>
<td>BONE</td>
<td>TM</td>
<td>Carnivore</td>
<td>145b</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2+</td>
<td>indet</td>
<td>BONE</td>
<td>TM,IS</td>
<td>Carnivore</td>
<td>1420c</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>LB</td>
<td>MSH</td>
<td>TM,IS</td>
<td>Carnivore</td>
<td>1208</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 or 4</td>
<td>Mammal</td>
<td>LB</td>
<td>TM</td>
<td>Carnivore</td>
<td>1448a</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

See description of table 5-2.
Table 5-4: Butchered specimens in FwJj 14B

<table>
<thead>
<tr>
<th>Size</th>
<th>Taxon</th>
<th>my side</th>
<th>Element</th>
<th>Portion</th>
<th>Marks Present</th>
<th>Agent</th>
<th>Stage</th>
<th>Action</th>
<th>Cat #</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cercopithecus sp.</td>
<td>R</td>
<td>HUM</td>
<td>MSH</td>
<td>CM</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>5233</td>
</tr>
<tr>
<td>2</td>
<td>Mammal</td>
<td>L</td>
<td>RIB</td>
<td>MSH</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing</td>
<td>4053a</td>
</tr>
<tr>
<td>2b</td>
<td>Suidae</td>
<td>R</td>
<td>Unciform</td>
<td>non-epiphyseal</td>
<td>CM</td>
<td>Hominin</td>
<td>indet</td>
<td>skinning, disarticulation</td>
<td>3055</td>
</tr>
<tr>
<td>2b</td>
<td>Bovidae</td>
<td>nid</td>
<td>RAD</td>
<td>MSH</td>
<td>CM</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>6021</td>
</tr>
<tr>
<td>2b</td>
<td>Bovidae</td>
<td>R</td>
<td>RAD</td>
<td>PEPI,PNEF</td>
<td>CM</td>
<td>Hominin</td>
<td>late</td>
<td>disarticulation</td>
<td>5128</td>
</tr>
<tr>
<td>2b/3a</td>
<td>Suidae</td>
<td>L</td>
<td>MC 3</td>
<td>PNEF</td>
<td>CM</td>
<td>Hominin</td>
<td>late</td>
<td>tendon removal from foot</td>
<td>5220</td>
</tr>
<tr>
<td>2b/3a</td>
<td>Bovidae</td>
<td>R</td>
<td>RAD</td>
<td>PEPI,PNEF</td>
<td>CM</td>
<td>Hominin</td>
<td>early</td>
<td>disartic, defleshing</td>
<td>6090a</td>
</tr>
<tr>
<td>2b/3a</td>
<td>Mammal</td>
<td>R</td>
<td>hyoid</td>
<td>horiz ramus</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>tongue removal</td>
<td>3124</td>
</tr>
<tr>
<td>2b/3a</td>
<td>Mammal</td>
<td>R</td>
<td>hyoid</td>
<td>ramus</td>
<td>IS</td>
<td>Hominin</td>
<td>mid</td>
<td>tongue removal</td>
<td>5222</td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td></td>
<td>Hyoid</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>R</td>
<td>FEM</td>
<td>MSH</td>
<td>CM</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>6038</td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>R</td>
<td>FEM</td>
<td>MSH</td>
<td>CM</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>6040</td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>R</td>
<td>FEM</td>
<td>PNEF</td>
<td>CM</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>5060</td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>L</td>
<td>HUM</td>
<td>DNEF</td>
<td>CM</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>3090</td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>R</td>
<td>HUM</td>
<td>DNEF</td>
<td>CM,PS</td>
<td>Hominin</td>
<td>early</td>
<td>disartic, deflesh, fragmentation</td>
<td>5099</td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>R</td>
<td>MAND</td>
<td>horiz ramus</td>
<td>CM</td>
<td>Hominin</td>
<td>indet</td>
<td>skinning</td>
<td>5214</td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>R</td>
<td>MAND</td>
<td>horiz ramus</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing</td>
<td>5097</td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>R</td>
<td>MP</td>
<td>MSH</td>
<td>CM</td>
<td>Hominin</td>
<td>indet</td>
<td>skinning</td>
<td>3165</td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>R</td>
<td>MP</td>
<td>MSH</td>
<td>ST,PS</td>
<td>Hominin</td>
<td>late</td>
<td>fragmentation</td>
<td>3035</td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>R</td>
<td>MT</td>
<td>MSH</td>
<td>CM</td>
<td>Hominin</td>
<td>late</td>
<td>tendon removal</td>
<td>3058</td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>R</td>
<td>TIB</td>
<td>MSH</td>
<td>CM,ST</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing, fragmentation</td>
<td>3096</td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>L</td>
<td>TIB</td>
<td>PNEF</td>
<td>CM</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>6037</td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>L</td>
<td>TIB</td>
<td>PNEF</td>
<td>ST</td>
<td>Hominin</td>
<td>late</td>
<td>fragmentation</td>
<td>4071a</td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>R</td>
<td>ULN</td>
<td>Olecranon</td>
<td>CM</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>5067</td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>L</td>
<td>ULN</td>
<td>px shaft</td>
<td>CM</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>5117</td>
</tr>
<tr>
<td>3</td>
<td>Bovidae</td>
<td>R</td>
<td>RIB</td>
<td>MSH</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing rib scraps</td>
<td>5230</td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>R</td>
<td>RIB</td>
<td>MSH</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing rib scraps</td>
<td>3088</td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>R</td>
<td>RIB</td>
<td>neck</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing rib scraps</td>
<td>3091</td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>R</td>
<td>RIB</td>
<td>MSH</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing rib bulk</td>
<td>3092</td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>R</td>
<td>RIB</td>
<td>MSH</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing rib bulk and scraps</td>
<td>5119a</td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>R</td>
<td>RIB</td>
<td>MSH</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing rib bulk and scraps</td>
<td>5119b</td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>R</td>
<td>RIB</td>
<td>MSH</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing or viscera removal</td>
<td>5261</td>
</tr>
<tr>
<td>3</td>
<td>Mammal</td>
<td>R</td>
<td>RIB</td>
<td>MSH</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing or viscera removal</td>
<td>3015</td>
</tr>
<tr>
<td>3+</td>
<td>Mammal</td>
<td>R</td>
<td>RIB</td>
<td>MSH,IS</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing rib bulk</td>
<td>6057</td>
</tr>
<tr>
<td>3</td>
<td>Suidae</td>
<td>R</td>
<td>MT-4</td>
<td>MSH</td>
<td>CM</td>
<td>Hominin</td>
<td>late</td>
<td>toe disartic, tendon removal</td>
<td>3132</td>
</tr>
<tr>
<td>3</td>
<td>Ungulata</td>
<td>R</td>
<td>THO</td>
<td>neur sp</td>
<td>CM</td>
<td>Hominin</td>
<td>mid</td>
<td>defleshing</td>
<td>5130</td>
</tr>
<tr>
<td>3a</td>
<td>Bovidae</td>
<td>R</td>
<td>Innominate</td>
<td>Ramus</td>
<td>CM</td>
<td>Hominin</td>
<td>early</td>
<td>defleshing</td>
<td>3005</td>
</tr>
<tr>
<td>3+</td>
<td>Mammal</td>
<td></td>
<td>CRAN</td>
<td>braincase</td>
<td>CM</td>
<td>Hominin</td>
<td>indet</td>
<td>skinning</td>
<td>3120</td>
</tr>
</tbody>
</table>

See description of table 5-2.
Table 5-5

Early Stage Actions

Defleshing hindquarters
Defleshing forequarters

Middle Stage Actions

Evisceration
Defleshing ribs
Defleshing head/mandible

Late Stage Actions

Disarticulation
Metapodial tendon removal
Fragmentation

*Skinning can occur early or late (interpreted as indeterminate)

Figure 5-2. Specimen 672 from GaJi 14 has a carnivore tooth score and carnivore tooth pits adjacent to a green fracture edge. Scale increments are millimeters.
Figure 5-3. Size 3 bovid calcaneum with stone tool cut marks and a typical bisected pit crocodile tooth mark from GaJi 14 (specimen 1034). Other tooth marks are circled. Scale increments are millimeters.

Figure 5-4. Fish spine (specimen 637 from GaJi 14) has a cluster of cut marks. Scale increments are millimeters.
Figure 5-5. Fragmented bovid size 2 mandible with chop-like marks (specimen 1025d from GaJi 14). Percussion striae are circled. Scale increments are millimeters.

Figure 5-6. Size 3 bovid left metacarpal (specimen 1007 from GaJi 14). This specimen has deep chop marks on the MSH which suggest core tool fragmentation (a, b). Cut marks on the distal articular surface indicate proximal phalanx disarticulation (c, d). Scale increments are millimeters.
Figure 5-7. Transverse cut marks on this posterior size 3 bovid metapodial suggest severing of the posterior tendon bundle, a necessary butchery action prior to fragmentation of the metapodials. (Specimen 902 from GaJi 14). Scale increments are millimeters.

Figure 5-8. Cut marks on this size 3/4 hippo proximal phalanx (specimen 7 from GaJi 14) indicate butchery of the foot. Scale increments are millimeters.
Figure 5-9. Small animals are size class 1 and 2. Large animals are size class 3 and above.

Table 5-6: Counts of butchered specimens and elements in GaJi 14

<table>
<thead>
<tr>
<th>Size class</th>
<th>NISP</th>
<th>early</th>
<th>mid</th>
<th>late</th>
<th>indet</th>
<th>MNE</th>
<th>early</th>
<th>mid</th>
<th>late</th>
<th>indet</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>7</td>
<td>12</td>
<td>9</td>
<td></td>
<td>7</td>
<td>5</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>8</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>6</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>16</td>
<td>16</td>
<td>12</td>
<td>1</td>
<td>14</td>
<td>7</td>
<td>9</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 5-7: Elbow specimen description and cluster diagnosis

<table>
<thead>
<tr>
<th>Cat #</th>
<th>Sex</th>
<th>Taxon</th>
<th>Element</th>
<th>Portion</th>
<th>Location</th>
<th>cluster #</th>
<th>Description</th>
<th>CM Count</th>
<th>DNEF</th>
<th>STD Length</th>
<th>STD Angle</th>
<th>Clus Diagnosis</th>
<th>Specimen Diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>101a</td>
<td>M</td>
<td>Bovidae</td>
<td>ULN</td>
<td>Olecranon</td>
<td>post face sup of med epicondyle</td>
<td>10</td>
<td>CM O 17 28 20 40.71 0.73 2.96 10.17 Def Def Def Def Def Def</td>
<td>Defleshing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>101b</td>
<td>M</td>
<td>Bovidae</td>
<td>UM</td>
<td>Olecranon</td>
<td>post face super femur</td>
<td>10</td>
<td>CM O 17 28 20 40.71 0.73 2.96 10.17 Def Def Def Def Def Def</td>
<td>Defleshing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>101c</td>
<td>M</td>
<td>Bovidae</td>
<td>UM</td>
<td>Olecranon</td>
<td>post face sup of med epicondyle</td>
<td>10</td>
<td>CM O 17 28 20 40.71 0.73 2.96 10.17 Def Def Def Def Def Def</td>
<td>Defleshing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>101d</td>
<td>M</td>
<td>Bovidae</td>
<td>UM</td>
<td>Olecranon</td>
<td>post face sup of med epicondyle</td>
<td>10</td>
<td>CM O 17 28 20 40.71 0.73 2.96 10.17 Def Def Def Def Def Def</td>
<td>Defleshing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

See Table 5-2 for all other specimens.

* Analysis is based on cluster attributes for the entire experimental humeral DNEF since the anatomical location of the archaeological cluster is not known.
Figure 5-10. Right medial portion of an ungulate size 3/4 humeral DNEF (specimen 101a from GaJi 14). Cluster 1 (a) and cluster 2 (b) both represent defleshing. Each cut mark is traced as a line and numbered on the photo using ImageJ 1.41o, and the perimeter which minimizes the area of the cluster is drawn around cut mark endpoints. Scale increments are millimeters, and a 10 mm section of the scale that was drawn in green and used to calibrate the photo for measurement is visible in (b).
Figure 5-11. Specimen 1064 from GaJi 14 is a size 3a bovid olecranon that was defleshed. Cluster 1 occurs on the anterior crest (a), cluster 2 occurs on the medial-superior aspect of the olecranon epiphysis (b), cluster 3 occurs on the medial face (c), cluster 4 has one cut mark that occurs on the medial aspect of the posterior spine (d), cluster 5 occurs on the posterior olecranon (e), and cluster 6 occurs on the lateral face, posterior to the semi-lunar notch (f). Scale increments are millimeters.
Figure 5-12. Defleshing cut marks on specimen 1101 from FwJj 14A a size 1 bovid right femoral PNEF (a). A percussion mark near a fracture edge is indicated by the arrow (b). Scale increments are millimeters.

Figure 5-13. Specimen 668 from FwJj 14A is a size 2 mammal humerus MSH has cut marks circles in green and a percussion mark indicating fragmentation shown with the arrow. Scale increments are millimeters.
Figure 5-14. Specimen 1024-97 from FwJj 14A is a size 3 bovid left tibial PNEF that preserves carnivore tooth marks, indicated by the arrow and cut marks, circled in green. Scale increments in millimeters.

Figure 5-15. This occipital specimen (1203a from FwJj 14A) suggests defleshing of the cranial base, probably to access the brain. Scale increments are millimeters.
Figure 5-16. Small animals are size class 1 and 2. Large animals are size class 3 and above.

Table 5-8: Counts of butchered specimens and elements in FwJj 14A

<table>
<thead>
<tr>
<th>Size class</th>
<th>NISP early</th>
<th>NISP mid</th>
<th>NISP late</th>
<th>NISP indet</th>
<th>MNE early</th>
<th>MNE mid</th>
<th>MNE late</th>
<th>MNE indet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>2</td>
<td>1</td>
<td></td>
<td>4</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>11</td>
<td>7</td>
<td>7</td>
<td>1</td>
<td>1</td>
<td>6</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>4</td>
<td></td>
<td>1</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>19</td>
<td>14</td>
<td>8</td>
<td>1</td>
<td>12</td>
<td>8</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>
Figure 5-17. Specimen 1022-97 is a size 3 mammal humeral DNEF postero-lateral fragment from FwJj 14A that represents defleshing. Scale increments are millimeters.
Figure 5-18. A size 4 hippo humeral DNEF fragment (specimen 103 from FwJj 14A) has clusters from different stages of hominin consumption. Cluster 1 on the anterior-medial face has a few short cut marks, and in conjunction with its anatomical location suggest disarticulation (a). Clusters 2-4 (b) suggest defleshing the larger muscles in the elbow. Scale increments in each photo are millimeters.
Figure 5-19. Specimen 5220 from FwJj 14B is a size 2b suid left 3rd metacarpal that has transverse cut marks on the medial aspect of the PNEF which represent tendon removal or skinning. Scale increments are millimeters.
Figure 5-20. Three butchered size 3 hyoid specimens from FwJj 14B. Specimens 3097 (a), 5222 (b), and 3124 (c) indicate tongue removal. Scale increments are millimeters.
Figure 5-21. Cut marks on this size 3 suid 4th metatarsal (specimen 3132 from FwJj 14B) indicate either tendon removal or toe disarticulation. Scale increments are millimeters.

Figure 5-22. Cut marks on this mandibular symphysis of a size 3 bovid (specimen 5124 from FwJj 14B) indicate skinning. Scale increments are millimeters.
Figure 5-23. Small animals are size class 1 and 2. Large animals are size class 3 and above.

Table 5-9: Counts of butchered specimens and elements in FwJJ 14B

<table>
<thead>
<tr>
<th>Size class</th>
<th>NISP</th>
<th>MNE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>early</td>
<td>mid</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>11</td>
<td>14</td>
</tr>
<tr>
<td>Total</td>
<td>14</td>
<td>15</td>
</tr>
</tbody>
</table>

Butchered NISP and MNE for FwJJ 14B
Figure 5-24. A right radial PEPI and PNEF of a size 2b bovid (specimen 5128 from FwJj 14B) with recent breaks. Evidence of disarticulation occurs on the anterior aspect just below the epiphysis in clusters 1 and 2 (a). Defleshing is also indicated by the cut marks on the medial PNEF in cluster 3 (b). Scale increments are millimeters.
Figure 5-25. This radial specimen (6090a from FwJj 14B) of a size 3 bovid represents defleshing and possible disarticulation. Cluster 1 (a) is suggestive of disarticulation, but the posterior portion of the fovea capitis was not cut-marked in any experimental butchery trial. Clusters 2 and 3 (b and c) occur on the PNEF and indicate flesh removal. Scale increments are millimeters.
Figure 5-26. Specimen 3090 from FwJj 14B is a size 3 bovid left humeral DNEF fragment with defleshing cut marks. Scale increments are millimeters.
Figure 5-27. Specimen 5099 from FwJj 14B is the lateral and posterior portion of a size 3 bovid right huermeral DNEF that has clusters of cut marks, green fracture and evidence of disarticulation and fragmentation. A percussion mark occur on the cortical bone near a fracture edge (a). The small cluster in (b) fits with the experimental disarticulation sample, and the other clusters represent defleshing. Clusters in (c) and (d) do not suggest removing the ulna from the olecranon fossa, but rather indicate that the triceps brachii muscle was filleted when these bones were still articulated. Scale increments are millimeters.
Figure 5-28. Specimen 5067 from FwJj 14B is the olecranon and proximal spine of a right ulna from a size 3 bovid with cut marks that suggest defleshing. These fragments do not conjoin, but were associated and have identical surface preservation. Scale increments are millimeters.

Figure 5-29. Specimen 5117 from FwJj 14B is a left proximal ulnar spine from a size 3 bovid with defleshing cut marks. Scale increments are millimeters.
Chapter 6. Conclusion

The paleoanthropology of *Homo erectus*’ carnivorous foraging

Going back in time to physically observe the moments in which *Homo erectus* used stone tools to butcher and consume flesh and break the limb bones to eat a large bovid’s marrow in a riparian stand of trees would provide a rich snapshot of that ancient instance of tool-assisted carnivory. But even if direct observation of that sort were possible, additional contextual evidence would be necessary to illuminate the ecological aspects of ancient human life that captivate the interest of paleoanthropologists.

The questions we ask about the paleoecology of carcass consumption are also constrained by the nature of the archaeological evidence and interlaced with biological and geological inferences that are applied to the past to add strength to archaeological interpretation.

Generally, paleoanthropologists ask two types of paleoecological questions about ancient carcass consumption. First, what ecological mode of carcass access did hominins practice at a site? Were ancient hominins hunting (Klein, 1989), confronting carnivores and stealing their kills (Bunn, 2001), stealing tree-stored leopard kills (Cavallo and Blumenschine, 1989), passively scavenging the marrow and flesh scraps from abandoned carnivore kills (Blumenschine, 1995), or luckily finding natural deaths? This question is answered with a detailed investigation of zooarchaeological evidence, is meant to infer hominins’ position in the ancient carnivore guild, and is similar to the explanations sought by community ecologists (see Morin, 1999).
The second type of question investigates how hominins’ carcass consumption changes across different areas of the ancient landscape. This investigation compares sites and builds arguments that draw upon additional lines of contextual evidence. For example, the types of tools at a site are related to raw material source locations (Braun, et al., 2009a, 2009b, Bunn, 1994), the positive and negative affordances in different habitats are linked to zooarchaeological traces (Blumenschine and Peters, 1998), and the nutritional value of carcass resources in different habitats is only beginning to be explored (Braun et al., 2010). The geological interpretations that supply habitat reconstructions along with the analyses of lithic material associated with faunal remains highlight the additional bodies of evidence that may be considered when hominin foraging is investigated on a geographic scale. These questions are analogous to the investigations of landscape ecologists (see Turner et al, 2001).

To be explicit, landscape-scale archaeological analyses rarely benefit from vast, lateral expanses of well-preserved zooarchaeological assemblages, and even the traces of butchery in a single fragmentary site can be difficult to interpret. Therefore, the fundamental obstacles for describing the paleoecology of hominin carcass consumption are an unclear understanding of how butchery with stone tools modifies the skeleton, and the lack of a method for unraveling the traces of carcass consumption amidst the action of taphonomic processes that distort and delete evidence of behavior. This dissertation contributes to resolving both of these problems.

Current interpretations of Plio-Pleistocene carnivory
The interpretations we can generate about ancient human carcass consumption are structured by the depositional context of zooarchaeological traces of butchery. Diverse taphonomic factors, including the hominin behavioral signals we are attempting to decipher amidst the competing signals of all other processes, influence bone assemblage composition, but ultimately geological processes preserve bone assemblages. (Behrensmeyer, 2000). So, before we can debate the paleoecology of carcass consumption of a fossil hominin taxon living during a certain time interval at specific site we must explore the context of geological preservation. For example, are butchery traces recorded as surface finds or in situ occurrences? Without a secure geological provenance it is difficult to reconstruct the precise paleohabitat where butchered bone was deposited and correlate different occurrences.

The state of a bone assemblage also influences the questions we can address about carnivory. Binford’s (1981) discussion of site integrity and resolution are informative concepts since they express whether archaeological remains are influenced by a single agent and how clearly an assemblage presents evidence of the multiple behaviors that contributed to its formation. An interpretation of carnivory therefore also depends on whether a bone assemblage represents a single butchered individual or multiple individuals, whether different animals can be distinguished, and whether humans were the only agent that brought bones to a site. For example can we determine a pattern of butchery that is common to many animals?

Processes of fragmentation significantly influence the interpretation of butchery behavior whether they are the result of human or carnivore consumption or post-depositional breakage, because they transform whole bones into less-complete units and
introduce greater uncertainty into identification of skeletal elements and discrimination of individual animals (Outram, 2004). Finally, cortical bone preservation is crucial to interpretations of ancient carnivory since it records many physical traces of human and carnivore carcass consumption. Therefore the amount of time an assemblage sat on the ground before it was buried and the degree of weathering it incurred, along with characteristics of the sediments and groundwater which encased fossil bone determine whether bone surface data can be investigated or whether less direct lines of evidence like fracture pattern or spatial association are used to argue about hominin carnivory (see Lyman, 1994).

Additionally, the same aspects of hominins’ carnivorous behaviors we seek to identify in zooarchaeological assemblages influence our understanding of the paleoecology of hominin carnivory because some interpretations are made from zooarchaeological data that are observable, and some are made from assumptions about data that is missing. For example, field butchery and transport of carcass parts to a residential site for complete consumption scatters different butchered elements across the landscape, so how do we identify this behavior in an assemblage and determine what happened at the other locality (Lupo, 2001)?

Two primary questions emerge from the discussion above, and this critical perspective should drive the proximate zooarchaeological analysis of butchered bone evidence as it reaches ultimate conclusions about the paleoecology of hominin carnivory; are sites in primary context, and do assemblages faithfully record their taphonomic history? With these ideas in mind, a brief review of East African zooarchaeological
evidence explores the evolution of hominins’ carnivorous foraging niche to contextualize the discussion of Okote Member carcass resource use presented in this dissertation.

**Pre-Oldowan**

The recent publication of alleged butchered bone from Dikika, Ethiopia dated to 3.4 Ma challenges conventionally accepted ideas about tool-assisted carnivory since it pushes the earliest use of stone tools back 800 Ka (McPherron *et al.*, 2010). These findings are interesting because they mirror the indirect evidence and arguments from a lack of evidence that are a part of many zooarchaeological interpretations of butchery. Dikika occurs geographically in an area whose only hominin community member is *Australopithecus afarensis*, and therefore butchered bone and its carnivorous implications are attached to this species. Two butchered bone specimens were discovered as surface finds and reported in this initial publication. These are a rib midshaft from a size 4 ungulate that possesses cut marks and percussion evidence and a femoral shaft of a size 2 juvenile bovid with cut and percussion marks along with recent breaks. However, I suggest that the geological and behavioral context of these findings is not sufficient to rewrite the evolutionary history of hominin carnivory without further supporting finds or lines of evidence. My comments echo the conclusions of Domínguez-Rodrigo *et al.* (2010) that cite the lack of associated *in situ* butchery evidence and suggest the more parsimonious explanation that the Dikika specimens bear butchery mark mimics more commonly referred to as trampling marks.
Most of the marks on these specimens match the generally accepted criteria for identification of stone tool slicing and percussion evidence, meaning that the cut marks are v-shaped with internal longitudinal striations, and percussion marks have similar internal striations, but these identification demands additional contextual evidence. As numerous authors have shown, cut and percussion mark mimics are possible, since after all any sharp-edge effector can slice bone, and fragmentation and pitting is possible for reasons other than hominin marrow bone fracture (Behrensmeyer et al., 1986, Dominguez-Rodrigo and Barba, 2006, Shipman and Rose, 1983, 1984). In fact the authors emphasize a different aspect of these marks’ morphology in the supplementary information in the Nature publication. They suggest that all experienced taphonomists who examined the specimens “made the general observation that these marks appear rather ‘heavy’ in that damage is massive and deep relative to stone tool inflicted marks [they] have seen on experimental, South African Middle Stone Age faunas, and Zagros Mountains Paleolithic faunas” McPherron et al., 2001:supplementary material 22). They characterize the Dikika bone modification as transitional between cut and percussion mark morphology, and suggest that this reflects an early adaptation to forceful expedient use of coarse-grained stone tool use during butchery. This interpretation may be so, but it seems like a post-hoc explanation in light of these surprising findings as opposed to a hypothesis that was tested. Likewise much of the discussion of mark morphology is presented in the supplementary information section. This is normal for a brief nature article, but curiously, all the negative information about mark identification is de-emphasized in the primary text. For example, the femur specimen has a clearly visible set of scratches that measure approximately 1 x 2 cm in the photograph (labeled mark I in the
supplementary information). This mark’s identification is inconclusive since it is very large and has micro-striations and compression of the bone that resemble both a cut and percussion mark, but it is linked to the fracture of the femur shaft.

Examining the behaviors implied by an anatomical discussion of butchery trace location adds another contextual line of evidence that addresses whether these traces represent butchery, but this approach also casts some doubt on the validity of these marks as evidence of carcass consumption. The authors discuss evidence of percussion on the lateral shaft of the rib specimen and on the juvenile femur shaft. In my estimation, there is no reason to intentionally fragment a rib. Ribs contain cancellous bone, not edible nutritious marrow and this structure also eliminates a sharp green fracture surface that might create a cutting edge. Likewise, the medullary cavity of juvenile long bones is a site of blood cell production, not the storehouse for fat-rich marrow as it is in adult animals, therefore, fragmentation would not provide a nutritious meal.

The authors cite the lack large clasts for raw material manufacture in the lake-margin paleohabitat context at 3.4 Ma, and also use the lack of raw material to justify the absence of lithic artifact assemblages on the landscape at this time interval. The supplementary information of their paper suggests that fractured stone tools in the strict sense of Oldowan flake and core types were not used for butchery, but a more expedient technology characterizes the earliest tool-assisted carnivory. As suggested above, this argument accommodates the archaeological context of the Dikika finds, but seems like a post-hoc explanation.

Without additional discoveries and lines of contextual evidence, it is difficult to determine whether McPherron et al. (2010) have observed physical evidence of
Australopithecus’ transition through the threshold of stone-tool assisted carnivory or whether they are looking at bones with naturally occurring damage that mimics hominin behavior. Documenting the origins of behavior with archaeological traces presents a special challenge though because, apparently from nowhere, evidence appears, and its earliest forms may not possess the classic diagnostic criteria that most analysts expect (see Haslam et al., 2009, Lyman, 1995).

The Earliest Oldowan

Like Dikika, surface finds of butchered bone from two sites in Ethiopia characterize the earliest traces of potential hominin butchery around the period in time when the Oldowan was the technological state of the art. Three specimens from Bouri, Ethiopia, dated to 2.5 Ma are suggested to represent stone tool butchery by *Australopithecus garhi* in a lake margin paleogeographic context (de Heinzelin et al., 1999). These bones also lack an in situ geological context and are not associated with an assemblage of stone tools. Despite the insecure surface context, the lack of associated stone tools is interpreted as tool curation in an area where raw material for tool manufacture does not exist.

The reported specimens include a bovid mandible with cut marks on the medial horizontal ramus that are interpreted as tongue removal, a large bovid tibia shaft fragment with cut, chop and percussion evidence, and a *Hipparion* femur with cut marks that are interpreted as dismemberment and filleting. These are realistic butchery behaviors in light of the location of the modifications present, but the authors conclude that evidence of
defleshing and marrow access reflect complete consumption of carcass resources, an ecological interpretation that seems speculative. I would add that tongue removal and marrow exploitation are likely to take place after more accessible carcass resources are consumed, but whether these were also enjoyed by *A. garhi* or another consumer is more difficult to establish especially since these specimens are not associated with *in situ* butchery assemblages. Here, early Oldowan age assemblages of butchered bone would add an important data set of additional taphonomic traces that would help establish whether early hominins were scavenging from carnivore kills. But again, only continued research will determine whether these assemblages exist at such an early period of hominins’ carcass exploitation.

At Gona, Ethiopia, dated to between 2.3-2.1 Ma, direct evidence of hominin carnivory is documented with *in situ* butchery evidence and surface occurrences, that are associated with lithic material (Dominguez-Rodrigo *et al.*, 2005). Other Type C sites (Isaac, 1978) exist in the Gona area, but butchery evidence is absent since cortical bone surfaces are typically not well preserved. Butchery trace fossils occur in different geological contexts at multiple locations, and the description of these fossils presents clear descriptions and butchery action interpretations of the bone surface modifications, which is a definite methodological strength. This Oldowan butchery evidence includes nearly 10 specimens that are mostly surface finds, and begins to document the variety of the skeletal portions that are butchered. An equid calcaneum has cut marks that represent skinning, and at a different site midshafts of 4 elements from either upper or intermediate limbs represent defleshing of size 1 through 3 animals. Different localities preserve a small bovid scapula and a rib shaft, where cut marks on the medial surface indicate
evisceration. The four localities increase the sample of modified fauna, and some specimens occur in assemblages associated with Oldowan tools, but still this is not the large-scale butchered faunal evidence that characterizes later time periods.

**Classical Oldowan**

During this time period, *Homo habilis* is the inferred tool maker and butcher that created the archaeological assemblages reviewed here. This period in the evolution of hominin carnivory provides the first high-resolution glimpses of carcass consumption and as an added benefit of these large assemblages and secure geological contexts incorporate other lines of evidence to contextualize the paleoecology of carnivory.

Kanjera, in Western Kenya preserves Oldowan assemblages in association with well preserved fauna at around 2.0 Ma in an edaphic grassland environment in a lake margin setting (Plummer et al., 1999). This site shows the earliest evidence of hominins exploiting grassland habitats (Plummer et al., 2009). An interesting occurrence of a hippo pelvis and lumbar vertebrae in the KS3 site occurs with stone flakes in close spatial proximity, and the authors argue that these tools were involved in butchery despite the lack of published descriptions of cut mark data. Another behavioral reconstruction drawn from the Kanjera assemblages indicates that hominins were gathering high-quality lithic raw material at sources and transporting them across the ancient landscape. So in sum, the evidence of butchery at Kanjera is not documented with direct butchery trace fossils but potentially indicates that hominins were accessing carcass parts from large animals,
and that a component of stone tool-assisted carnivory involved a mobile foraging strategy where stone was moved between landscape facets.

Koobi Fora, the region on the eastern shore of Lake Turkana in northern Kenya contains classic and Developed Oldowan sites in the interval of 2.1-1.6 Ma, particularly during the KBS Member (Harris and Isaac, 1997). A recently reported site, FwJj 20, from the Upper Burgi Member near the basin margin in the Il Dura area preserves a large assemblage of stone artifacts and butchered bone at around 1.95 Ma. The site is reconstructed as a lake margin habitat and preserves direct butchery evidence of aquatic fauna including fish, turtle and crocodile body parts along with cut and percussion marks on terrestrial fauna from size class 2 to 5. Lithic raw materials seem to be locally abundant and the butchered taxa demonstrate the broad dietary range of early hominins.

The FLK 22 (Zinjanthropus) level at Olduvai Gorge (Leakey, 1971) and the diverse interpretations of hominin carnivory it generated dominated the discussion of Oldowan hominin paleoecology in the recent past (see Chapter 1; Plummer, 2004, Lupo and O’Connell, 2002). To be fair, this assemblage has nearly pristine cortical preservation and is a large, in situ assemblage of lithic artifacts and butchered bone, so it deserves the critical attention. Different researchers were interested in interpreting whether the Zinj assemblage represented hominins’ early access to meaty carcasses or scavenging from carnivore kills, and defined different sub-assemblages for study, and used different bone portion coding conventions, ultimately reaching diverse conclusions. The apparent inability of actualistically-based zooarchaeology to reach a productive consensus about the ecology of hominin carnivory was interpreted as a signal to abandon
these zooarchaeological studies (see Domínguez-Rodrigo, 2008, Lupo and O’Connell, 2002).

From its interpretations and comparisons to actualistic models of tooth mark and butchery mark frequency, two competing ideas emerge. In the lake margin setting at Olduvai around 1.8 Ma, hominins accessed fully fleshed carcasses (Bunn and Kroll, 1986, Domínguez-Rodrigo, 1997, Egeland et al., 2004), or hominins were consuming some flesh from long bones, but these were largely defleshed and instead consumption focused on marrow and head contents (Blumenschine, 1995, Capaldo, 1997, Selvaggio, 1998).

During Oldowan times it seems that tool-assisted carnivory gained importance in the diet of the early members of genus *Homo*, that is, if the increase in archaeological visibility of butchery trace fossils reliably reflects this ecological shift. Regardless, from the earliest pre-Oldowan butchery finds to the large lithic and faunal assemblages that characterize the late Pliocene, hominin carnivory seems to shift from an expedient foraging strategy to a focused exploitation of both terrestrial and aquatic vertebrate carcass resources. The fact that selectivity and transport of raw material, and evidence of aquatic animal butchery in lake shore paleoenvironments are visible in large assemblages suggests that hominins had conceptual resource maps of their landscapes and organized their foraging to target unevenly distributed resources at Kanjera, the paleo-Olduvai basin and East Turkana (Braun et al., 2010, Plummer, 2004).

**Okote Age butchery traces**
At around 1.5 Ma, large assemblages of lithic material and associated fauna begin to appear in the record, and add important data for examining hominin carnivory. This abundance of sites also allows comparisons of their paleoenvironmental reconstructions to illuminate the paleoecology of ancient carnivory.

The ST site complex in Peninj, Tanzania preserves many lithic occurrences that are often associated with faunal remains at around 1.5 Ma (Domínguez-Rodrigo, *et al.*, 2002). These assemblages are all deposited on top of a laterally extensive paleosol horizon that is interpreted as representing a nearly 3.5 square kilometer snapshot of an ancient landscape. Developed Oldowan occurrences are dominated by flakes, but contain core forms as well, and some of the artifacts seem to be made from non-local raw material. The authors also interpret the proportions of flake types and core size to represent transport of already reduced cores onto the site, which were utilized, reduced further and ultimately discarded. In general, cortical bone preservation is not good, so the observations of butchery traces that would link the lithic and faunal evidence are absent. Still the authors use the co-occurrence of stones and bones to indicate hominin butchery. Unfortunately, this argument does not rely on direct evidence of butchery and modern landscape observations show that scatters of bone from individual carcasses can occur on the ground surface without any influence from human behavior (Behrensmeyer and Dechant Boaz, 1980).

However, one assemblage, ST4, has good bone preservation and is used to characterize the patterns of carnivory at Peninj. Carnivore activity is recorded by tooth marks in the assemblage, but percussion and cut mark butchery traces indicate the hominins were also accessing meat and marrow at ST4. But, cut marks are not extremely
common and are restricted to long bone shafts. This proportion of upper limb midshaft specimens with cut marks is used to argue that hominins were defleshing meaty limb elements but the authors also cite the absence of long bone end portions and indicate that it renders potential disarticulation cut marks analytically invisible. These interpretations are logical but they are drawn from a database that adds significant uncertainty because it amalgamates different faunal occurrences from the ST site complex. The proportion of specimens in long bone segment or portion categories that bear a type of butchery trace (cut marks for example) are calculated based on the total number of specimens of that bone or portion in the total ST complex archaeofauna. This is inaccurate because it lumps different assemblages that could have been created within different butchery contexts into a general group, and primarily because the ST4 assemblage is the only assemblage in the sample where butchery traces can be identified on cortical bone surfaces. Therefore conclusions about hominin carnivory from the preserved paleolandscape at Peninj are based mainly on the co-occurrence of lithic artifacts and bone that are presumed to be butchered. Identifying the butchery actions which took place in different assemblages and on bones that potentially represent individual animals could illuminate whether hominins enjoyed early access to carcasses and completely consumed them, but this does not seem possible with the state of bone preservation at Peninj.

Okote Member sites at Koobi Fora share some of the analytical challenges introduced by poor bone preservation. Specifically, sites on the Karari Ridge are characterized by leached and chalky bone preservation, eliminating the possibility of using bone modification preserved on the cortical surface (Bunn et al., 1980).
FxJj 20 is a site on the Karari Ridge dated to around 1.5 Ma, that consists of the contemporaneous 20-Main and 20-East occurrences and 20-AB and 20-South which occur stratigraphically above the other localities (Harris and Isaac, 1997, Isaac and Harris, 1978). In the modern gully, the stratigraphic horizon in which FxJj 20 is preserved has a low-density scatter of lithic artifacts and fossil bone, but the excavated site complex documents very high densities of artifacts in association with fauna. This suggests that the surrounding paleohabitat was used extensively by foraging hominins and that areas of artifact concentration that may represent butchery evidence (but unfortunately only spatial association, an indirect line of evidence exists). At 20-East, a mandible of *Paranthropus boisei* was discovered in situ along with reddened patches of sediment that may represent some of the earliest traces of hominin-controlled fire. Two possible cut-marked bone specimens occur from 20-Main, and the site report indicates that during excavation, bone fragments tended to occur in patches. Unfortunately, since it is impossible to differentiate the natural background scatter of bones from those introduced during hominin consumption, not all of the fauna can be taken as direct evidence of butchery. But overall, the abundant lithic evidence and multiple archaeological horizons suggest that hominins repeatedly used this location, and the association of fauna is suggestive of carcass consumption. However, it is not possible to precisely reconstruct the butchery actions that took place on different animals.

At FxJj 50, bone preservation is still relatively poor, but some of the best at any locality in the Karari sub-region (Bunn *et al.*, 1980). This site occurs at the confluence of the axial proto-Omo river and a smaller channel draining the basin margin, which contained a nearby gravel bar that was the source for the site’s large lithic assemblage.
The bone assemblage at FxJj 50 has a small proportion of cut marked and percussion-marked fossils and has a typical under-representation of limb bone ends, in conjunction with carnivore tooth marks, making it difficult to determine whether hominins were consuming whole carcasses or flesh scraps and marrow from scavenged carcasses. Butchered specimens exist in the well-preserved component of the assemblage including conjoining green-fractured fragments of a *Megalotragus* humerus which may belong to the same element as the large bovid distal humerus that bears disarticulation cut marks. The butchery actions of disarticulation and fragmentation in the absence of defleshing cut marks points toward an example of hominins’ late stage consumption of a scavenged carcass. However, obviously taking the entire assemblage into consideration would be ideal, but only a small component has suitable cortical surfaces and possesses traces of hominin or carnivore consumption.

In general evidence of hominin carnivory is observed in the fauna associated with dense lithic archaeological accumulations during the Okote time period, but detailed inferences about the nature of carcass consumption are limited by the uncertainties introduced when bone surfaces are poorly preserved. But beginning in the Early Pleistocene, large East African localities like Peninj, Olduvai Gorge and Koobi Fora record archaeological traces in diverse paleolandscape contexts allowing a comparison between regions where different habitats would have offered diverse sets of resources including stone tool material, plant foods, water, and refuge, along with different ecological contexts (Blumenschine and Peters, 1998). One such context, the abundance and diversity of carnivore taxa would determine interspecific carnivore competition and influence carcass availability (Brantingham, 1998, Van Valkenburgh, 2001).
Comparisons with the Okote butchery assemblages

Isaac’s central place model of site formation highlights the aspects of hominin behavior that contribute to archaeological assemblage formation, including transport of stone and carcass parts to a locality where tool-assisted carnivory took place (Isaac, 1983). This movement of resources across the landscape is an important aspect of the changing ecological position of hominins. Specifically, it establishes the way in which hominins relate with their surroundings, by using technology derived ultimately from a natural source, flakable stone, to mediate their feeding behavior. The transport of tools to assist feeding behaviors is documented in many species, including birds, sea otters, and a few primates including, capuchins and chimps (Haslam et al., 2009).

The earliest traces of butchery seem to reflect a more expedient form of tool-assisted carnivory, although this behavior is difficult to resolve due to its sparse archaeological existence. When larger accumulations of butchery evidence appear in the archaeological record, they still include interpretive challenges, but it is clear that butchery tends to occur in two distinct contexts, large assemblages near stone tool sources (e.g. FwJj 20), and at smaller localities distant from raw material source where non-local stone must be imported (e.g. Kanjera). Therefore, Pliocene and the earliest Pleistocene butchery evidence seems to suggest that carcass parts were transported to areas on the landscape where stone tool material was locally abundant, similar to Potts’ stone cache model (Potts, 1988, 1991, 1994).
Tool curation seems to be the major ecological innovation during Okote Member times, and this behavior is appreciated with a comparison between sub-regions of the Eastern Turkana basin. The bone assemblages analyzed in this dissertation, GaJi 14 from the Koobi Fora Ridge and FwJj 14 A and B from Ileret provide a comparison with the Karari Ridge sites FxJj 20 and FxJj 50 that illuminates different patterns of tool use during carnivorous foraging. For the first time in the record of human carnivory, the Ileret and Koobi Fora sites document large occurrences of butchered bone that are distant from raw material sources, and importantly they also indicate that tools were highly valued and not discarded once butchery was completed (Bunn, 1994, Pobiner et al., 2008). In contrast, sites on the Karari Ridge preserve evidence of butchery that occurs near local raw material sources.

In my analysis, I show that hominins at these localities consumed both large and small carcasses, enjoyed early access to large carcass parts and completely consumed them, eating both meat and marrow. My analysis revises Bunn’s (1994) description of a foraging strategy based on earlier surface finds where hominins moved quickly through Ileret and the Koobi Fora Ridge consuming flesh from carcasses and in some cases ignoring marrow. I suggest less of an opportunistic strategy where stone tools were carried in case carcasses were encountered, and favor an interpretation where foraging involved expectations about the carcass resources that were likely to occur in distinct habitats on the landscape. Tools were curated during the Okote member with the expectation that they would be needed for future butchery, suggesting a more efficient use of raw materials in light of the energetic costs of acquiring them. In general this
suggests an advancement in Okote Member foraging behavior where technology was involved in planning for future situations as opposed to satisfying present demands.

Future research directions

I plan to continue experimentally documenting the skeletal traces of the butchery process. It would be informative to study a carefully generated experimental model of the sequence of early, middle and late stage butchery actions. This goal was initiated by the sequential actualistic models of the 1990’s (e.g. Blumenschine, 1995 etc.), but given the discussion of their methods in this dissertation, it would be beneficial to re-analyze their data, and gather additional experimental trials in order to approach the interpretation of butchery traces from a different perspective. I suggest that future actualistic butchery experiments should document the specific skeletal elements and portions that preserve butchery traces of different stages of consumption by hominins and carnivores. While this resolution of observation will require many experimental replications to contribute statistically sound conclusions, it would be very informative when analyzing a fragmentary archaeological butchery assemblage to understand the likelihood that observed bone surface modifications represent the true sequence of butchery behaviors that created each archaeological specimen. For example, future experimentation should document how bone surface traces are imparted on an individual skeleton during a particular sequence of defleshing, disarticulation and hammerstone fragmentation butchery actions, as well as carnivore defleshing and bone destruction.
With a high-resolution understanding of which bone modifications are likely to occur at specific skeletal portions when an individual animal is butchered, and knowledge of how these traces are distributed among assemblages of bone fragments as whole bones are broken by hammerstones or carnivores, it would be possible to simulate likely bone assemblages that reflect sequences of butchery and carnivore consumption which define testable paleoecological hypotheses of hominins’ role in assemblage formation.

Greater analytical resolution would improve the behavioral resolution of paleoecological interpretations of zooarchaeological data, and obviously discovering additional Early Stone Age butchery assemblages would provide additional evidence. It would be particularly useful to compare the butchered remains of a single animal to typical butchered palimpsest assemblages where small, butchered bone fragments of many animals are collected.

Reconstructing Early Stone Age hominin carnivory

It can be argued that taphonomically informed zooarchaeology teaches us more about what we do not know about the paleoecology of the earliest tool-assisted carnivory than what we can infer with great confidence. But this is the nature of scientific progress, since we can proceed with refining and retesting hypotheses.

The uncertainties surrounding the ecological mode in which Oldowan hominins accessed mammalian carcasses are also conditioned by the sparse butchery traces that occur prior to the period in which the FLK Zinjanthropus assemblage was created. As this dissertation shows, it is difficult enough to reconstruct the paleoecology of carcass
consumption from fragmentary bone assemblages with excellent cortical preservation and abundant traces of butchery, let alone isolated surface finds. Yet, even alleged butchery modifications without any supporting contextual evidence are used to describe a carnivorous foraging strategy for Early Stone Age hominins (e.g. McPherron et al., 2010). The allure of discovering the earliest evidence of butchery behavior is strong, but poses a significant analytical challenge since novel archaeological techniques are required to locate and verify the origins of stone tool butchery. A recent discussion of the material traces of primate tool use explores the challenges in detecting evidence of butchered bone and its associated technology as it crosses the threshold from invisible to identifiable (Haslam et al., 2009, Lyman, 1995). These claims require even more substantial evidentiary support which must come from future actualistic work describing the traces of tool-assisted carnivory along with other lines of argument about hominin paleobiology.

Less controversial is one of the major implications of this dissertation. The butchery evidence analyzed here suggests that Okote hominins (and probably earlier taxa) were generalist carnivores that used technological means to exploit carcass resources. In contrast to previous archaeological interpretation of ancient carnivory that linked an early or late access ecological strategy to a hominin taxon (e.g. Binford, 1981, Dominguez-Rodrigo, 1997), I suggest that Okote hominins occupied a liminal role in the carnivore guild, practicing a variety of behavioral ecological strategies including passive and confrontational scavenging, directed foraging in landscape facets where carcass resources were common, and hunting of small animals. Specifically, I suggest that these behaviors changed to in response to the momentary ecological contexts like the facet-
specific context of carnivore competition, inter- and intra-species hominin competition and group member provisioning, and the encountered state of carcass completeness. These ephemeral contingencies, which are so difficult to reconstruct, are precisely the paleoecological contexts that archaeologists aim to reconstruct. They are the sort of questions that must be pursued with future actualistic research which revises analytical methods, and from multiple analytical directions with additional lines of contextual evidence.
Appendix A: Large ruminant elbow musculo-skeletal anatomy figures


Figure A-1: Left elbow joint structure.

Figure A-2: Left elbow joint.

Figure A-3: Deep structures of the right forearm, lateral aspect.
Figure A-4: Superficial structures of the right forearm, lateral aspect.


Figure A-5: Deepest structures of the right forearm, medial aspect.

Figure A-6: Deeper structures of the right elbow and forearm, medial aspect.

Figure A-7: Deep Structures of the elbow and forearm of the right thoracic limb, medial aspect.

Figure A-8: Superficial structures of the arm and forearm, right thoracic limb, medial aspect.

Figure A-9: Deeper structures of the right lateral shoulder.

Figure A-10: Deep structures of the right lateral shoulder.

Figure A-11: Superficial structures of the lateral shoulder of the right thoracic limb.

Figure A-12: Vessels, nerves and muscles of the right thoracic limb, elbow, medial aspect.

Figure A-13: Vessels and nerves of the medial shoulder and arm, right thoracic limb.

Figure A-14: Brachial plexus and adjacent structures of the left thoracic limb, medial aspect.
Appendix B: Butchered specimen descriptions

*Specimens are organized by site and size class. The number refers to the site catalog number. The taphonomic traces on each specimen were described to aid in photography and to guide a more formal taphonomic analysis and taxonomic diagnosis.

**GaJi 14**

**Size 2**

1025d – Bovid size 2 Hemi-mandible horizontal ramus. Two clusters of very deep cut marks with some crushing in the deepest mark which resembles a chop. A patch of percussion microstriae extends off of a green fracture edge, and the inferior aspect which contains the mandibular nerve is fragmented. Cannot determine which side this horizontal ramus belongs to, so it is not possible to determine whether cut marks occur on the medial or lateral face. Specimen suggests defleshing and fragmentation. (Photo 1010).

107 – Mammal size 2/3 Rib MSH. Cluster of wide cut marks and associated striae occur on the lateral face of this rib MSH. These suggest defleshing of bulk rib flesh. (Photo 957).

1035 – Mammal size 2/3a Rib MSH. Clusters of cut marks on the medial surface of the rib MSH. The lateral surface is more weathered (WS 1 / 2) and has cut marks and more weathered marks that lack internal striae but are probable cut marks. Suggest rib defleshing and possible viscera removal. (Photo 1026, 1028).

1065 – Mammal size 2/3a Rib MSH. Cut mark on the medial or lateral surface, but can’t identify side. Suggests defleshing (Photo 1110).

724 – Mammal size 2/3a right Hemi-mandible gonial angle. Clusters of cut marks on the medial and lateral faces of the gonial angle region of this fragment suggest defleshing of the masseter muscle. Probable mandible disarticulation and tongue butchery depending on whether the head was accessed early or scavenged. (Photo 800, 801, 802, 803).

***1034 – Bovid size 2/3a left Calcaneus. This specimen has crocodile tooth marks, possibly has terrestrial carnivore tooth marks and contains at least one good cut mark with internal striae, and many other striae that are harder to determine. All of these marks occur on the anterior-lateral aspect of the calcaneus body. Suggests hominins disarticulated the foot of a carcass scavenged from a crocodile. (Photo 1023, 1025).***

1066 – mammal size 2b/3a MP NEF frag. Percussion striae indicate fragmentation. (Photo 1111).

1055 – Bovid size 3 right Humerus MSH. Cut marks and scrape marks on the midshaft suggest defleshing. (Photo 1084, 1085, 1086).
1007 – Bovid size 3 left Metacarpal distal end. The distal end specimen displays green fracture, and a few indeterminate pits, and one definite large percussion pit with microstriae emanating from its center. Other chop marks occur near the fracture edge and suggest fragmentation using a sharp edged hammer like a core. Cut marks on the medial face of the medial condyle and the inferio-anterior aspect of the middle ridge of the lateral condyles suggest separation of ligaments necessary for toe disarticulation. (Photo 979, 980, 981, 982, 983).

1047(abc) – Bovid size 3 left Metacarpal shaft. This specimen is in poor surface condition (WS 1/2) and has expanding matrix distortion which increases the space between longitudinal cracks. However relatively well-preserved portions of bone surface display oblique and transverse cut marks on the anterior, medial and posterior faces of the shaft. Suggests removal of tendon bundles and possible skinning. (Photo 1064, 1067, 1068, 1070, 1072, 1073).

109 – Bovid size 3 left Metapodial MSH. This specimen has a very well preserved surface and displays percussion striae extending off of a green fracture edge, a percussion notch, with crushing and percussion pits in its center, cut marks and fungus damage. Suggests tendon removal, skinning, and fragmentation, and also shows a clear difference between percussion pits and fungus damage. (Photo 960, 961, 962).

902 – Bovid size 3 Metapodial distal end. Cut marks occur on the posterior face of the DNEF, superior to the articular bone of the condyles, suggesting separation of the posterior tendon bundle. (Photo 809).

6 – Bovid size 3 right Metatarsal MSH. Clusters of sub-parallel oblique cut marks running up the shaft. Suggests tendon removal. Specimen also has green fracture suggesting fragmentation. (Photo 952).

1119 – Bovid size 3 right Navicular-Cuboid. Transverse cut marks across the anterior lip and the medial face of the articular process suggest disarticulation of the foot keeping the navicular-cuboid attached to the metatarsal and the astragalus and calcaneum attached to the tibia. (Photo 1174, 1175).

1096 – Bovid size 3 left Radius MSH. Cut marks on the anterior medial msh suggest defleshing. Specimen has poor surface (WS 1/2). (Photo 1173).

1079 – Bovid size 3 left Scapula posterior blade. This fragmentary specimen displays cut marks and scrape marks on the posterior border, and medial and posterior basins which suggests defleshing. Specimen is in many refitting pieces (Photo 1120, 1121, 1122, 1123, 1124, 1125, 1127, 1128, 1129, 1131, 1132, 1134, 1135, 1136, 1137, 1138, 1139).

1052 – Bovid size 3 left Tibia MSH. Clusters of short cut marks surrounded by matrix which probably obscure other cut marks. (Photo 1076, 1077).
531 – Bovid size 3 Rib MSH. Cut marks occur on anterior or posterior intercostal edge. Can’t tell which since side cannot be identified. One cluster occurs next to fungus damage. Suggests removal of intercostal flesh. (Photo 790).

1058 – Mammal size 3 right Femur MSH. Clusters of cut marks on the linea aspera and shaft proximal to the plantaris fossa suggest defleshing. (Photo 1093).

1021 – Mammal size 3 Rib MSH. Cut marks on the medial and lateral faces suggest defleshing and possible evisceration. (Photo 997, 1001, 1002, 1003, 1004, 1008).

1033 – Mammal size 3 Rib MSH. Cut mark on the anterior or posterior intercostal edge of the rib MSH suggest intercostal defleshing. (Photo 1020, 1021).

1038 – Mammal size 3 Rib MSH. Clusters of cut marks on the lateral face near the neck of the rib and around the medial, anterior, and posterior surfaces of the shaft. Suggests complete rib defleshing and possible evisceration. (Photo 1034, 1035, 1037, 1039).

1085b – Mammal size 3 Rib MSH. Clusters of cut marks on the lateral face of the rib MSH. This specimen is WS 1 and has other damage that obscures most of the cortical surface. (Photo 1152).

1089 – Mammal size 3 Rib MSH. Few light and long cut marks on the medial surface of the rib MSH suggest evisceration. (Photo 1057, 1058, 1059).

604 – Mammal size 3 left Rib neck. Cut marks on the anterior-lateral face of the rib neck, next to the fossa suggest bulk muscle defleshing. (Photo 793).

1061 – Mammal size 3 Tibia DNEF. Percussion striae and deep chop-like percussion pits suggest fragmentation, although only recent breaks occur in this specimen, and the surface is partially exfoliated. (Photo 1095).

1008 – Mammal size 3 right Scapula neck. Cluster of cut marks on neck suggest defleshing. Specimen is slightly rounded, limiting visibility of cut mark cross section. (Photo 984, 985).

1064 – Bovid size 3a left Ulna olecranon process. Cut marks on superior, posterior, medial and lateral faces of the olecranon process. Surface is partially weathered (WS 1) but cut marks are visible. Suggests defleshing of radio-ulna muscles and possibly muscles attaching to superior aspect of olecranon. (Photos 1100, 1101, 1103, 1104, 1106, 1008).

1071 – Mammal size 3b Thoracic vertebrae neural spine. Cut marks on right and left sides of the spine suggest defleshing of back muscles. (Photo 1114, 1115, 1116, 1117).

1026ab – Mammal size 3b/4 left Scapula neck fragment. Cut and scrape marks on the medial surface of the neck suggest defleshing. (Photo 1011, 1012).

7 – Hippo size 4 proximal phalanx. Transverse cut marks on the medial or lateral shaft face suggest slicing of foot tendons. (Photo 954).

1092 – Mammal size 3b/4 Ilium shaft fragment. Cut marks on the superior, inferior and lateral face of ilium shaft suggest defleshing. (Photo 1096, 1097, 1098).

1001 – Mammal size 3/4 long bone MSH fragment. Percussion marks and striae on fracture edge indicate fragmentation. (Photo 977, 978).

1013 – Mammal size 3/4 radius MSH. Clusters of cut marks on medial or lateral face in different directions suggest defleshing. (Photo 989, 990).

510 – Mammal size 3/4 Rib MSH. Cut marks on the medial face suggest defleshing or evisceration (Photo 968).

1019 – Mammal size 3/4 Tibia PNEF. Cut marks on pnef shaft and across recent fracture edge suggest defleshing. (Photo 994).

101a – Ungulate size 3/4 right Humerus DNEF. Clusters of many cut marks suggest defleshing. (Photo 956).

1017 – Ungulate size 3/4 rib MSH. Cut marks on the medial or lateral face of the rib shaft suggest defleshing or evisceration. (Photo 992).

1036 – Ungulate size 4 left distal MC. Cut marks on the anterior edge of the lateral condyle, the posterior-lateral and medial faces of the DNEF suggest toe disarticulation. (Photo 1029, 1030, 1032).

543 – Bovid size 4 MP MSH. Two clusters of cut marks on the anterior surface of the shaft suggest skinning of the metapodial. (Photo 969, 971).

1044ab – Mammal size 4 Femur PNEF. Percussion striae on green fracture edge indicate fragmentation. (Photo 1050, 1051).

1045 – Mammal size 4 Rib MSH. Clusters of cut marks on the lateral face suggest defleshing. (Photo 1061, 1063).

1056 – Mammal size 4 Scapula frag. Clusters of cut marks on the anterior border, anterior basin and medial basin suggest defleshing the scapula. Marks suggest removing a lot of flesh. (Photo 1088, 1089, 1090, 1091, 1092).
1090 – mammal size 4 left ilium blade fragment. Cut marks and scrape marks on the inferior surface of the ilium blade suggest defleshing. (Photo 1160, 1162, 1164, 1167, 1170).


108 – Mammal fibula MSH fragment. Can’t ID size or taxon on this fibula long bone. Deep cut marks suggest defleshing of the lower limb. (Photo 958).

568 – Mammal Rib MSH frag. Cut marks on the lateral-distal edge of this rib indicate defleshing intercostal flesh. (Photo 973, 974, 975).

1086f – Mammal Rib MSH frag. Cut marks on the lateral face of the rib suggest defleshing (Photo 1155).

637 – FISH spine. Cluster of many cut marks in sub-parallel orientation suggest defleshing. (Photo 794).

689 – FISH spine. Two clusters of cut marks on this fish spine suggest defleshing. (Photo 796, 797).

**FwJj 14A**

*Size 1*

1101 – Mammal size 1 Femur PNEF. Poor surface preservation but a few clusters with a few long cut marks, including some on the proximal linea aspera, and some indeterminate striae near a green fracture edge that may be related to fragmentation. The poor surface makes it hard to identify modifications (Photo 673, 674).

*Size 2*

668 – Mammal size 2 Humerus MSH. Two deep parallel cut marks indicate flesh removal, and a percussion pit and percussion striae on a green fracture edge opposite the pit suggests fragmentation (photos 581, 582, 583).

1205 - Mammal size 3 Rib MSH. Clusters of cut marks on the lateral face of a rib MSH suggest removal of rib flesh. Very fine sediment abrasion marks on the medial face of the rib show the extreme contrast in these mark types. (Photo 696, 697).

9 – Mammal size 2 or 3 Ilium blade fragment. Large patch of overlapping striae that seem like overlain scraping and cut marks. These marks extend off a recent fracture edge. Suggests flesh removal, possibly scraps attaching to ilium blade. (Photo 544).

1122,1125 – Bovid size 2b Left Tibia PNEF. Clusters of oblique cut marks on medial aspect of anterior tibial crest. Indicates defleshing. Sediment abrasion also exists on this specimen but the interior of the marks are a different color than the bone surface (Photo 683, 684).

610 – Mammal size 2b Humerus MSH. Clusters of cut marks along the midshaft. Suggests defleshing. (Photo 566).

1014-97 - Mammal size 2b Ilium ramus. Clusters of cut marks on medial face and deep, chop and scrape marks on the inferior ramus which suggest defleshing of hip muscles. (Photo 632, 633, 637).

1226- Mammal size 2b Left Ilium ramus. A cluster of marks on the superior medial face of the ilium near the sacral articulation. Suggests defleshing. (Photo 678).

1020-97 – Mammal size 2b Rib MSH. Clusters of cut mark on lateral face suggests flesh removal. (Photo 644, 645).

1028 – Mammal juvenile size 2b Thoracic vertebrae epiphyseal plate. Transverse cut marks across the epiphyseal plate suggests separation of rib vertebrae from other sections (Photo 651).

1112 – Bovid size 2b/3a Mandible horizontal ramus. This specimen has cut marks near a recent break on the inferior border and multiple very deep indeterminate pits which are not easy to identify, but may be crocodile tooth marks or large chopping or percussion marks. Possibly indicates skinning or defleshing (Photos 679, 680).

1003-97 – Bovid 2b/3a right Metacarpal distal end. This specimen has clusters of short cut marks on epicondylar area of the posterior and the lateral faces, and up the distal shaft of the posterior face. These suggest skinning and removal of the posterior tendons (Photos 593, 594, 596).

1107 – Bovid size 2b/3a Tibia MSH. Percussion mark with associated striae on the posterior face next to a green fracture edge. Suggests fragmentation. (Photo 675).

1289 – Mammal size 2b/3a Rib neck. Cut mark on anterior or posterior surface of neck suggests removal of intercostal flesh (Photo 714).

321,348 – Mammal size 2b/3a Ulna MSH spine. Cut mark on the posterior aspect of the MSH region. Suggests defleshing. (Photo 532).
1093 – Suid size 2b/3a right Astragalus. Cut marks on medial and lateral sides of proximal condyles, the lateral portion of the posterior side of the distal condyle and the anterior-lateral portion of the non-epiphyseal section. These marks suggest disarticulation of the foot from the tibia and the astragalus from the calcaneum, navicular and cuboid. (Photos 666, 667, 669, 671).

1001-97 - Mammal size 2b/3a Mandible ascending ramus. Specimen is moderately heavily weathered (WS 2/3), but cut marks on medial and lateral faces of ascending ramus suggest defleshing or disarticulation of mandible. (Photo 586).

Size 3

1019-97 – Bovid size 3 left Femur PNEF. Cluster of sub-parallel cut marks on the posterior PNEF distal to the lesser trochanter. Specimen also has green fracture. Suggests defleshing (Photo 641).

5007 – Bovid size 3 right Mandible coracoid process. Clusters of cut mark on anterior and medial faces of the coracoid process. Suggests mandible defleshing since disarticulation would mark the lateral aspect. (Photo 739).

1015-97 – Bovid size 3 Metapodial DNEF. Dense clusters of cut marks on the medial or lateral face of the DNEF of this metapodials fragment. Suggests removal of posterior tendon bundle. (Photo 771).

1203a – Bovid size 3 Occipital. Clusters of transverse cut marks on inferior portion, anterior of the foramen magnum. Some marks occur in recessed areas, ruling out trampling marks. Suggests head removal. (Photos 692, 694, 695).

1 – Bovid size 3 right Patella. Transverse cut marks on anterior-superior tendon attachment suggests disarticulation of knee joint. (Photo 547, 548).

***1024-97 – Bovid size 3 left Tibia PNEF. This specimen has cut marks and carnivore tooth marks on the medial face. Green fracture is present but tooth marks do not occur near edges, and percussion marks are absent. (Photo 650).

2034a – Bovid size 3 left Tibia MSH. Percussion striae occur on green fracture edge, suggesting fragmentation. (Photo 734).

6073 – Bovid size 3 left Ulna spine. Weathered specimen but cut marks are still visible on the posterior aspect of the Ulnar spine in the PNEF region. Suggests flesh removal. (Photo 744).

1056 – Mammal size 3 Femur MSH. Clusters of cut marks on posterior face near linea aspera suggest defleshing (Photo 656, 658).
1397a – Mammal size 3 Femur MSH. Percussion striae near green fracture edge suggest fragmentation. (Photo 723, 724).

418 – Mammal size 3 left Humerus NEF. Two sub-parallel cut marks on this near-epiphyseal shaft specimen suggest defleshing. (Photo 554).

***1022-97 – Mammal size 3 left Humerus DNEF. Cut marks on posterior lateral face of DNEF region. This location suggests either defleshing or disarticulation. (Photo 647).

2611a – Mammal size 3 Humerus PNEF. Cut marks crossing green fracture edge on medial face, just medial of the deltoid tuberosity. Suggests defleshing. (Photo 779).

140 – Mammal size 3 Lumbar pre-zygopophysis. Most of the specimen is covered in matrix. The cut marks are inferior to the pre-zygopophysis, probably made during removal of the muscles above the transverse processes. (Photo 522).

1170 – Mammal size 3 Lumbar neural spine. Transverse cut marks on the right and left side of the neural spine. Suggests defleshing of the hip muscles. (Photo 689, 690).

1002c-97 – Mammal size 3 Radius MSH. Specimen is WS 1 and has possible fungal damage on the surface. Still cut marks with internal striae are visible, and some cross the green fracture edge. Suggests defleshing.

6063 – Mammal size 3 Rib MSH. Cut marks on anterior intercostal edge suggests removal of intercostal flesh removal. (Photo 742).

6084 – Mammal size 3 Rib MSH. Cut marks on posterior intercostal edge suggests removal of intercostal flesh. (Photo 745).

***102 – Bovid size 3a left Ischium ramus. Clusters of cut marks on lateral face of ischium ramus posterior to the acetabulum. The multiple sub-parallel clusters of marks suggesting filleting, but do not exclude disarticulation of the leg. (Photo 786).

Size 4

1221 – Hippo size 4 Cervical vertebrae. This specimen is WS 1, so some possible cut marks are rounded and identifiable. A single cut mark exists on the inferior non-articular portion of the centrum, and indeterminate striae which may be cut or trample marks occur on the posterior face of the transverse process and the posterior epiphyseal plate. It is not clear whether these marks represent removal of neck musculature or separation of the head and neck from the body to make other butchery actions easier. (Photo 704).

103 – Hippo size 4 Humerus left DNEF. This specimen has a WS 1 surface, but cut marks occur on areas where WS is 0, indicating that additional marks may be obscured. Clusters of cut marks and a scrape mark occur on the anterior-medial and medial face of the DNEF. Suggests defleshing. Green fracture also occurred (Photo 541, 542, 543).
431 – Mammal size 4 Rib MSH. Clusters of cut marks on the anterior and superior-lateral aspects of the rib MSH. Suggests bulk and intercostal rib flesh removal. (Photo 557, 559, 560).

6346 – Mammal size 4 Rib distal shaft. One cluster of long, deep cut marks and other clusters of short, shallower marks on either the medial or lateral face of the distal portion of a rib. These marks could represent viscera removal or defleshing. (Photo 760).

1210 – Mammal size 4+ Rib MSH. Multiple clusters of short cut marks on the lateral face of the rib MSH. Suggests defleshing. (Photo 702).

1012-97 – Hippo size 5 Cervical vertebrae. Cut marks occur around both transverse processes, the inferior face of the centrum, the pre-zygopophyses, and the inferior aspect of the anterior epiphyseal plate. These marks occur suggest defleshing of the neck musculature and possible disarticulation of the head and neck from the trunk. (Photo 603, 608, 610, 611, 614, 616, 617, 618, 623, 624, 626).

**FwJj 14B**

Size 1

5233 – *Cercopithecus* Hum shaft frag. “cluster of sub-parallel cm down the posterior face of this Cercopithecine humerus. some very fine marks, but some wide marks with clear striae, def not sed abrasion. some long marks running somewhat longitudinal, and some short marks, on the distal shaft. on the distal shaft.” Oblique cut marks from defleshing. Photo 913,914,916.

Size 2

4053a – Mammal size 2 Rib frag. Has multiple cut marks but can’t tell whether cut mark cluster is on interior or exterior face of rib. Defleshing.

3055 – Suid size 2b right unciform. “very wide cm, seems to be from separating carpals, transverse cms that may be disartic or skimming. I think this a suid unciform from a size 3“. photo 827, 1867. Photo 827 (Figure #) shows separating the foot from the radio-ulna (and skinning around the carpals). The process that attaches the posterior-lateral ligament/tendon was severed because these cut marks were deep and occur right on its superior face. Skinning is indicated by the transverse cluster of cut mark on the posterior aspect. The skinning marks seem shallower.

5128 – Bovid size 2b right radius proximal end. Disarticulation cut marks on anterior-lateral epiphyseal edge (Photo 899) and anterior edge just below epiphysis (photo 900). Another cluster of two small marks occurs right near the radial tuberosity. This cluster suggest some meat removal or disarticulation while soft tissue covered the elbow joint.
6021 – Bovid size 2b radius MSH. Side and px,ds, indeterminate. Oblique, subparallel cluster of marks on either medial or lateral face, suggests defleshing, but cannot tell amount of flesh removed (Photo 928).


6090a – Bovid size 2b right radius. Disarticulation cluster of transverse cut marks on posterior-lateral corner of proximal epiphysis suggests disarticulation from humerus (Photo 942). Oblique cut marks on radial tuberosity suggest defleshing (Photo 940, 941).


5222 – Mammal size 2b hyoid. Indeterminate striation which may be a single cut mark on anterior aspect of horizontal ramus (Photo 909).

6038 – Bovid size 3 Femur MSH. Clusters of short defleshing cut marks on and around linea aspera. (Photo 935).

3090 – Bovid size 3 left Humerus DNEF. set of thin deep oblique cut marks in a subparallel cluster. On lateral face proximal of epicondyle. Specimen also has green fracture but no percussion marks. Suggests defleshing. (Photo 835).

***5099 – Bovid size 3 right Humerus DNEF. Multiple cut mark clusters on a green fracture with a percussion mark with internal microstriae. On lateral face this specimen has cut marks that cross fracture edge and percussion mark with straie and a large cluster of cut marks in multiple length and direction; some are short and deep, some are long and shallow. (Photo 879, 881). Cluster of short oblique marks and long longitudinal marks on posterior face superior to the lateral epicondyle (Photo 883). Cut marks on posterior face superior to medial epicondyle (Photo 885). These cut mark suggest defleshing of humerus and hammerstone fragmentation with possible disarticulation.

5097 – Bovid size 3 Mandible horizontal ramus. Cluster of cuts on inferior margin and two longer marks on the medial face. Probably related to defleshing. No photo.

5214 – Bovid size 3 mandible left horizontal ramus. Cluster of cuts just inferior of I3 alveoli. Seems to be related to skinning the lower jaw. (Photo 906).

3035 – Bovid size 3 MP MSH frag. Cannot ID side of fore/hind. Parallel percussion microstriae patches on medial and lateral posterior edges related to anvil slippage. A negative scar from bone flake removal occurs with the platform on the posterior edge near where anvil marks occur. Percussion marks and striations occur on other locations as well. (Photo 819, 821).
3165 – Bovid size 3 MP MSH frag. Cluster of cut marks on anterior face of MSH (Photo 861). Probably related to skinning.

3058 – Bovid size 3 MT msh frag. 2 Clusters of short cm on posterior face, probably related to removal of tendons. (Photo 830).

5230 - Bovid size 3 Rib MSH. Clusters of cut mark on intercostal edge, and a few on the lateral face. Defleshing rib flesh scraps (Photo 910, 911).

3096 - Bovid size 3 Tib MSH. Percussion striae on lat face and green fracture (Photo 840), and cut mark clusters on lateral face (Photo 841, 842, 844). Can’t tell how much flesh was removed, but was defleshed before fragmentation.

***5067 – Bovid size 3 Ulna. Cut marks on the medial posterior aspect of the olecranon process and on the spine. Hard to tell if this is disarticulation or defleshing (Orientation is longitudinal. Does this help?) (Photo 874, 875).

5117 – Bovid size 3 Ulna shaft. Proximal shaft, has cut marks on posterior edge and medial face. Defleshing the radioulna (Photo 891, 892, 893).

5060 – Mammal size 3 Femur PNEF. Sets of cut marks on posterior face that extend off of green fracture edge. Defleshing.

6040 – Mammal size 3 Fem MSH. Posterior and post-lateral face has cluster of cut marks. Defleshing. (Photo 936, 937).

3097 – Mammal size 3 Hyoid. Two deep cuts on superior or inferior edge of posterior process, can't tell direction of bone though. Cluster of finer marks on edge of horizontal ramus. Tongue removal. (Photo 845, 846).

3088 – Mammal size 3 Rib MSH. 2 clusters of cut mark on intercostal edge. Suggests defleshing rib flesh scraps. (Photo 832, 833).

3091 – Mammal size 3 left rib neck. Anterior rib, post-lateral face of neck. Suggests defleshing rib scraps. The rest of the rib is pretty exfoliated. (Photo 836).

3092 – Mammal size 3 Rib MSH. Can’t tell if transverse cut mark are on internal or external surface of ribs. Removing bulk rib flesh. (Photo 837, 838, 839).

5119a – Mammal size 3 Rib MSH. Clusters of cut marks near either anterior or posterior intercostal edge. Suggest defleshing ribs. (Photo 894). Non-refitting match with 5119b. Both specimens reflect total rib defleshing.

5119b – Mammal size 3 Rib MSH. Clusters of cut marks near either medial or lateral face. Suggest defleshing ribs or upper viscera removal. (Photo 894). Non-refitting match with 5119a. Both specimens reflect total rib defleshing.
5261 – Mammal size 3 Rib MSH. Clusters of marks on medial or lateral face. Suggests defleshing bulk or upper viscera removal. (Photo 921).

3015 – Mammal size 3 Rib MSH. Cluster of marks on medial or lateral face. Suggests defleshing bulk or upper viscera removal. (Photo 946).

4071a – Mammal size 3 Tibia PNEF. Patches of percussion microstriae on posterior-lateral edge near green fracture. (Photo 866, 967).

6037 – Mammal size 3 Tibia PNEF. Two cut marks on posterior muscle scars on PNEF. (Photo 932).

3132 – Suid size 3 MT4. Ant-post cm up post curve of med condyle suggests toe disarticulation. Filleting cm up the muscle ridge on the post shaft of the MT suggest posterior tendon removal. (Photo 851, 853, 854).

***5130 – Ungulate Thoracic vertebrae neural spine. Can’t ID right or left side but filleting marks on one side. Suggest removal of flesh over spine. (Photo 901).

3120 – Mammal size 3+ braincase. Cut marks suggests skinning of animal possibly before brain removal. (Photo 848).

6057 – Mammal size 3+ rib frag. Lateral face of rib MSH has a few cut marks. Suggest defleshing rib bulk flesh. (Photo 938, 939).

***3005 – Bovid size 3a Innominate. Ant-post direction cut marks on the ramus of the ischium near the pubic symphysis. Med-lat cut mark adjacent to the pubic symphysis. Ant-post direction cm on the ramus above the ‘sup to the pub symph’ section. Suggests defleshing of the innominate (Photo 815, 816, 817).
Bibliography


Lupo, K. D. & O'Connell, J. F. 2002. Cut and tooth mark distributions on large animal


McPherron, S. P., Alemseged, Z., Marean, C. W., Wynn, J. G., Reed, D., Geraads, D.,


Pobiner, B. L. 2008. Apples and oranges again: comment on ‘Conceptual premises in
experimental design and their bearing on the use of analogy: an example from experiments on cut marks’. *World Archaeology* 40:446-479.


Curriculum Vitae

Stephen R. Merritt

Education
2011 Ph.D. in Anthropology, Rutgers, the State University of New Jersey
2005 M. A. in Anthropology, Rutgers, the State University of New Jersey
2000 B. S. in Evolutionary Anthropology, Rutgers, the State University of New Jersey

Academic and Related Positions
Present: Adjunct Faculty, Introduction to Physical Anthropology, Anthropology, Sociology and Social Work, Seton Hall University.
Present: Teaching Assistant, Anthropology, Rutgers University.
Fall 2009. Teaching Assistant. Latin American Anthropology, Rutgers University.
Fall 2007, 2008: Instructor, Expository Writing, English Department, Rutgers University.
Fall 2003. Teaching Assistant, Introduction to Human Evolution, Rutgers University.

Publications