1-1-2006

Success in Identification of Experimentally Fragmented Limb Bone Shafts: Implications for Estimates of Skeletal Element Abundance in Archaeofaunas

Travis Rayne Pickering
Indiana University

Charles P. Egeland
Indiana University

Amy G. Schnell
Indiana University

Daniel L. Osborne
University of Nebraska - Lincoln, dosborne2@unl.edu

Jake Enk
Indiana University

Success in Identification of Experimentally Fragmented Limb Bone Shafts: Implications for Estimates of Skeletal Element Abundance in Archaeofaunas

Travis Rayne Pickering*

Department of Anthropology, Indiana University, Bloomington, Indiana, 47405, USA; Center for Research into the Anthropological Foundations of Technology (CRAFT), Indiana University, Bloomington, Indiana, 47405, USA; Stone Age Institute, 1392 West Dittemore Road, Bloomington (Gosport), Indiana, 47433, USA; Institute of Human Evolution, University of the Witwatersrand, WITS 2050, Johannesburg, South Africa

Charles P. Egeland, Amy G. Schnell

Department of Anthropology, Indiana University, Bloomington, Indiana, 47405, USA; Center for Research into the Anthropological Foundations of Technology (CRAFT), Indiana University, Bloomington, Indiana, 47405, USA; Stone Age Institute, 1392 West Dittemore Road, Bloomington (Gosport), Indiana, 47433, USA

Daniel L. Osborne, Jake Enk

Department of Anthropology, Indiana University, Bloomington, Indiana, 47405, USA

A strong pattern of high hindlimb representation (especially tibiae) was recognized in our survey of zooarchaeological analyses that included limb bone shafts in estimates of element abundance in assemblages from the Old and New Worlds, from widely spread time periods and with various hominid species that acted as bone accumulators. Inter-element differences in bone mineral density and carcass transport behavior by hominids do not explain the pattern satisfactorily. We hypothesized that shaft fragments of hindlimb elements (especially tibiae) might be more "intrinsically identifiable" than are fragments from other limb bones, and constructed an experiment to test this idea. Whole limb bones were sectioned into shaft fragments of various sizes using a bandsaw. An experienced faunal analyst (TRP), who was uninvolved in the bone selection and preparation, was required to identify the fragments as accurately as possible to specific skeletal element. Identification bouts were divided into 14 individual sorts, each consisting of 24 randomly assigned specimens. Sorts were constructed to replicate an increasing degree of communion across three stages: two "Stage I" sorts contain large specimens, four "Stage II" sorts contain smaller specimens and eight "Stage III" sorts contain the smallest specimens.

* E-mail: trpicker@indiana.edu

Refitting and guessing were not allowed and fragments identified to a non-element-specific category (i.e.: upper limb segment, humerus *or* femur; intermediate limb segment, radius *or* tibia; lower limb segment, metacarpal *or* metatarsal; limb bone shaft only) were not counted as a correct identification. Of 336 total specimens, 195 (58.0 %) were correctly identified to element. Overall, the differences in proportions of skeletally identified fragments for all six elements are not statistically significant. This finding seemingly falsifies the hypothesis that shaft fragments from hindlimb elements (especially tibiae) are more intrinsically identifiable than are fragments of other limb bones. However, our study also highlights the need for additional testing of the hypothesis since most actual archaeofaunas preserve many more specimens with complete or nearly complete diaphyseal circumference than does our experimental sample, which is composed entirely of specimens with preserving <50 % of their original circumferences. Our results suggest that bone specimen cross-sectional information, mostly lacking in the experimental sample but not in real archaeofaunas, is one of the most important classes of data on which accurate identification of shaft fragments are made.

Keywords: FAUNAL ANALYSIS; ZOOARCHAEOLOGICAL ASSEMBLAGES; SKELETAL PART FREQUENCY; HINDLIMBS; DIAPHYSES, CROSS-SECTIONAL GEOMETRY

Introduction

A common zooarchaeological pattern of artiodactyl skeletal part representation, sometimes called the "Klasies Pattern" (Bartram, 1993; Bartram & Marean, 1999) or the "Type II Pattern" (a pattern based on a Type II error, i.e., "the erroneous acceptance of the hypothesis that similar ancient patterns are indicative of similar processes") (Cleghorn & Marean, in press; Marean *et al*., 2001), shows a predominance of head and foot elements (e.g., Binford, 1981, 1984; Klein, 1976; Klein *et al*., 1999; Outram, 2001; Perkins & Daly, 1968; Stiner, 1991a,b,c, 1994, 2002). It has been argued that this pattern is spurious in its indication of hominid carcass collecting behavior, and instead reflects methodological deficiencies in which limb bone shaft fragments[1] are ignored by researchers during the excavation, recovery and identification stages of analysis (e.g., Bartram, 1993; Bartram & Marean, 1999; Bunn, 1991; Bunn & Kroll, 1986;

Marean, 1998; Marean & Kim, 1998; Marean *et al*., 2004; Pickering *et al*., 2003; Turner, 1989).

Because of their high bone mineral density and low nutritional yields, limb bone shaft fragments typically survive the rigors of density-mediated destruction throughout the biostratinomic and diagenetic phases of faunal assemblage formation better than many other elements and element portions (reviewed in Bartram & Marean, 1999; Cleghorn & Marean, in press; Marean & Cleghorn, 2003; Marean & Kim, 1998; Marean *et al*., 2004; Pickering *et al*., 2003). This means that limb bone counts based on less durable epiphyses will systematically underestimate their abundances. An exception is the case of metapodials, which have relatively dense and thus well preserved distal condyles. This often leads to a perception of inflated metapodial representation in faunas in which bone counts are calculated solely on epiphyses. Combined with high skull counts (themselves based largely on the preferential

---

1. Defined here as ungulate humerus, radioulna, femur, tibia and metapodial diaphyseal pieces that preserve <100% of the complete original circumferences (see Pickering, 1999; Pickering *et al*., 2003).

preservation of highly mineralized dental specimens), high metapodial counts result in the Type II Pattern.

Obviously, such a methodologically determined pattern is undesirable if one's goal is to reconstruct the behavior of hominids, so at least three approaches have been suggested to facilitate the incorporation of limb bone shaft fragments in zooarchaeological studies. Marean *et al*. (2001; see also Marean *et al*., 2004) have summarized and reviewed these approaches, which include fraction summation (Klein & Cruz-Uribe, 1984), manual overlap (Binford, 1978; Bunn, 1982, 1986; Bunn & Kroll, 1986; Morlan, 1994) and automated overlap (Marean *et al*., 2001; Münzel, 1986). The details of these approaches contrast. However, in addition to their common goal of including limb bone shaft fragments, they are also *all predicated on the ability to accurately identify shaft fragments*.

Pickering *et al*. (2003; see also, Marean *et al*., 2004) summarized data on eight Stone Age archaeological sites analyzed by researchers using fraction summation and overlap approaches and with full incorporation of limb bone shafts. An interesting pattern of skeletal part frequencies is apparent when examining closely those and other similarly generated data (Table 1). There is a strong pattern of hindlimb predominance and more specifically tibiae in most cases in terms of number of identified specimens (NISP) and minimum numbers of elements (MNE) for each zooarchaeological sample (defined by combinations of layers or components and by taxon/taxa body size) from these sites. This pattern is even more interesting considering that the samples are associated with different hominid taxa and are derived

from widely disparate geographies, time intervals and paleoenvironmental contexts. Thus, it seems appropriate to hypothesize that this pattern might be an artifact of the relative higher "intrinsic identifiablity" of certain elements rather than a reflection of bone-collecting behavior by prehistoric hominids. Here, we present a test of this hypothesis, in which one of us (TRP), a faunal analyst with 13 years' experience analyzing modern and archaeofaunal assemblages of large vertebrates, identified fragmented limb bone midshaft specimens of mixed white-tailed deer (*Odocoileus virginianus*) elements.

Materials and Methods

Experimental sample and design

The following experiment was constructed *without* the involvement of the experimental subject. The remains of medium sized (i.e., Size Classes 2 and 3; see, Brain, 1981) artiodactyls are a prominent feature in faunal assemblages worldwide. Because they were locally available from K.W. Deer Processing (Bloomington, Indiana), we chose to the use the bones of Size Class 2 white-tailed deer for our experiments, a sample that included six each of the following elements: humerus, radius, metacarpal, femur, tibia and metatarsal. Each bone was sectioned into shaft fragments with a MarMed™ diamond bandsaw. Sectioning was done with the saw so that we could produce standardized fragments and thus maintain as much comparability between sorting sets (see below) as possible. Although fragment production by hammerstone percussion or carnivore feeding would have resulted in

Fragmented limb shafts

Assemblage	Site type[4]	Taxon[5]	NISP[6]						MNE[6]					
			HM	RD	MC	FM	TA	MT	HM	RD	MC	FM	TA	MT
Bugas-Holding	A	2	—	—	—	—	—	—	**19**	17	15	13	19	11
		4	—	—	—	—	—	—	14	15	12	12	19	7
Agate Basin Main Folsom Component	B	2	23	21	15	28	25	12	10	13	10	11	12	7
		4	63	61	**149**	80	79	132	34	39	**84**	33	39	78
Agate Basin Agate Basin Component	B	4	**27**	11	6	**19**	19	8	**9**	3	2	**6**	6	3
Agate Basin Main Hell Gap Component	B	4	14	11	6	**19**	18	8	**6**	3	2	**6**	6	3
Clary Ranch	B	4	86	66	54	73	**99**	38	**42**	25	21	18	29	19
Kobeh	C	2	404	336	319	478	**665**	307	64	47	38	63	**96**	36
Die Kelders 1 Layer 10 and 11	D	1	21	12	12	**42**	25	17	8	4	3	**9**	7	5
		2	3	8	20	**25**	25	15	2	2	5	5	7	4
		3	15	8	11.5	19	**40**	11.5	**7**	4	2	3	6	6
		4	19	16	18.5	32	**59**	23.5	8	6	4	7	**10**	8
Porc Epic	D	1a	49	108	10	**207**	119	8	13	57	4	**81**	22	3
		1	137	237	95	**438**	291	106	24	50	14	**116**	36	18
		2	260	328	234	**747**	543	285	22	47	17	**119**	40	24
		3	86	45	71	**158**	155	112	9	9	10	**29**	14	16
		4	17	8	16	**21**	25	14	3	1	2	**6**	2	2
Swartkrans Member 3	E	1	7	13	14	14	**27**	12	—	—	—	—	—	—
		2	42	32	22	54	**119**	44	—	—	—	—	—	—
		3	35	20	15	28	**85**	31	—	—	—	—	—	—
		4	11	5	4	**17**	17	5	—	—	—	—	—	—
Swartkrans Member 2	E	1	**9**	3	4	12	17	2	—	—	—	—	—	—
		2	22	21	11	30	**63**	21	—	—	—	—	—	—
		3	15	8	5	11	23	2	—	—	—	—	—	—
		4	11	2	0	1	8	0	—	—	—	—	—	—
Swartkrans Member 1	E	1	29	47	20	2	10	3	—	—	—	—	—	—
		2	41	19	12	47	**94**	25	—	—	—	—	—	—
		3	11	5	1	35	64	7	—	—	—	—	—	—
		4	1	0	0	3	15	3	—	—	—	—	—	—
BK, Olduvai	F	1 and 2	25	18	15	**32**	**15**	24	—	—	—	—	—	—
		3 and 4	70	33	21	46	26	23	—	—	—	—	—	—
MNK (Main), Olduvai	F	1 and 2	8	4	5	20	**29**	5	—	—	—	—	—	—
		3 and 4	8	10	3	16	69	6	—	—	—	—	—	—
		≥4	**39**	4	20	13	22	18	—	—	—	—	—	—
FLK Level 22, Olduvai	G	1 and 2	6	4	1	17	9	10	6	6	6	8	**12**	10
		3	—	—	—	—	—	6	14	16	10	14	**19**	6

Table 1 (page 100, left). Summary of archaeological studies that provide NISP and MNE and utilized limb bone shaft fragments[1,2,3].

1. Adapted and updated from Pickering et al. *(2003: 1477-1478, Table 4).*

2. Abbreviations: NISP = number of identified specimens; MNE = minimum number of elements; HM = humerus; RD = radius; MC = metacarpal; FM =femur; TA = tibia; MT = metatarsal.

3. Site country and data sources: Bugas Holding, USA (Rapson, 1990); Agate Basin and Clary Ranch, USA (Hill, 2001); Kobeh, Iran (Marean & Kim, 1998); Die Kelders, South Africa (Marean, 1998; Marean et al.*, 2001); Porc Epic, Ethiopia (Assefa, 2002); Swartkrans, South Africa (Pickering* et al.*, 2005, in press); BK and MNK (Main), Tanzania (Monahan, 1996); FLK Level 22, Tanzania (Bunn, 1986).*

4. Site Type: A, Late prehistoric open; B, Paleoindian open; C, Mousterian cave; D, Middle Stone Age cave; E, Developed Oldowan cave; F, Developed Oldowan open; G, Oldowan open. Temporally associated hominid species: Bugas Holding, Agate Basin, Clary Ranch, Die Kelders, Porc Epic = Homo sapiens*; Kobeh =* H. neanderthalensis*; Swartkrans =* H. ergaster/erectus, Australopithecus robustus*; BK and MNK (Main) =* H. ergaster/erectus, A. boisei*; FLK Level 22 = early* Homo, A. boisei.

5. Taxon presented as animal size class (1 – 4), based on Brain's (1981) well-known classificatory scheme constructed for bovids.

*6. **Bold** = highest value.*

more archaeologically "realistic" fragments, those fragments would have also been idiosyncratic in form, reducing their comparability.

The experiment was comprised of three stages of limb shaft fragment identification, with each stage replicating an increasing degree of comminution. Preparation of specimens for each stage of identification was initiated by the removal of epiphyses as indicated by a line drawn around the circumference of the periosteal surface, transverse to the long axis of the bone and with reference to important anatomical landmarks (Figure 1).

For Stage I, limbs were further sectioned as illustrated in Figure 1, with each element split coronally, resulting in anterior and posterior full lengths of shaft. Those lengths were then each split again, this time sagittally, resulting in a total NISP of four for each element. These steps were repeated for the separate bones involved in the Stage II identification sample. However, the four specimens obtained per element after those procedures were then each cut transversely, resulting in a NISP of eight for each element. The entire sectioning sequence from Stage II was repeated on the separate bones involved in Stage III. Those eight pieces from each element were each split again transversely, resulting in a NISP of 16 for each element.

Each stage of fragmentation was divided into individual "sorts" consisting of 24 specimens that were analyzed as discrete samples (Figure 2). Stage I contained two sorts, Stage II contained four sorts, and Stage III contained eight sorts[2]. Catalogue numbers were assigned randomly to specimens, and specimens were assigned randomly to sorts. Sorts were given to the analyst in a random sequence.

For this experiment, the analyst was instructed to consider each sort as he would an actual archaeofauna, where accuracy

2. The experimental assemblage is housed in Pickering's Old World Zooarchaeology Laboratory, Indiana University. We will be pleased to allow other analysts access to it in order that our results might be tested independently. Interested researchers should contact Pickering.

Anterior   Lateral

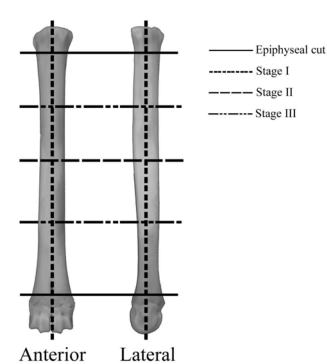Epiphyseal cut
Stage I
Stage II
Stage III

Figure 1. Schematic of a complete metapodial illustrating the segmentation of whole limb bones in the experimental sample by analytical stage as described in the text. Epiphyses were removed for each element at the following anatomical regions: (1) *Humerus*: proximal epiphysis, immediately distal to the deepest invasion of the neck onto the diaphysis; distal epiphysis, immediately proximal to the coronoid fossa; (2) *Radius*: proximal epiphysis, immediately proximal to the radial tuberosity; distal epiphysis, immediately proximal to the ulnar notch; (3) *Femur*: proximal epiphysis, base of the lesser trochanter; distal epiphysis, base of the supracondylar fossa; (4) *Tibia*: proximal epiphysis, immediately proximal to the postero-lateral nutrient foramen; distal epiphysis, through the midpoint of the distal anterior tubercle; (5) *Metapodials*: proximal epiphysis, immediately distal to the posterior foramen; distal epiphysis, immediately distal to the anterior foramen.

in identification is paramount. Thus, guessing was forbidden and identifications were maximally conservative, meaning that a fragment was always assigned to a grosser level of identification (i.e., to segment or simply as a limb bone shaft fragment) when at all ambiguous. Attempts at refitting specimens were not permitted.

Some Words on Refitting and Meaningful Levels of Skeletal Part Identification

There are various levels of bone specimen identifiability in archaeological analysis, the most favorable being identification as a specific skeletal element; in the case of artiodactyl limb bone shaft fragments that means correctly identifying a specimen as a humerus, radioulna, metacarpal, femur, tibia or metatarsal. Refitting of limb bone shaft specimens can yield important dividends with the marked increase of that portion of an assemblage that is ultimately identified correctly to specific elements (e.g., Bunn, 1982, 1986; Bunn & Kroll, 1986; Marean & Kim, 1998; White, 1992). Some commentators, in response to the landmark refitting work conducted on the Kobeh Cave (Iran) Neanderthal fauna (Marean & Kim, 1998), suggested the costs of such a time-consuming effort far outweigh the benefits.

We do not agree with those criticisms, but we also realize that refitting is not a realistic strategy in all archaeofaunas, especially those severely

affected by diagenetic breakage and destructive excavation techniques. For example, Pickering (1999) spent four months, without much success, conducting refit work on the ungulate faunas from Sterkfontein Member 5 (South Africa). Because of the difficulty in removing fossils from the heavily calcified breccias that typify most of Member 5, many specimens were splintered during excavation and preparation. Although it might seem that this would enhance rather than reduce success at refitting, this was not the case because excavation and preparation breaks are not necessarily "clean." Instead, initial fracture surfaces are often broken multiple times with additional attempts to free a fossil from its tightly adhering matrix. Resulting splinters of very small bone that preserve contacts with conjoining pieces are often lost or crushed to powder.

In such circumstances, identification to specific skeletal element might not possible for many specimens, even for the most skilled analyst. However, in those cases, that skilled analyst can often categorize a limb bone shaft as deriving from an upper limb element (i.e., the humerus or femur), an intermediate limb element (i.e., the radioulna or tibia) or a lower limb element (i.e., the metacarpal or metatarsal), based on an assessment of the fragment's cortical thickness, apparent or projected cross-sectional shape and other features such as nutrient foraminae (see, Domínguez-Rodrigo, 1999; Barba & Domínguez-Rodrigo, 2005). Fortunately, because of the disparate distribution of nutritional resources across the upper, intermediate and lower limb segments of artiodactyls, this grosser level of identification is still informative behaviorally. Shaft portions of upper and intermediate bones are encased in meat,
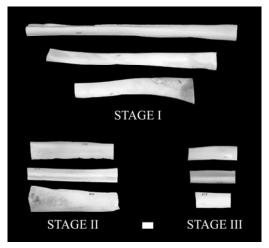

Figure 2. Representative examples of bone specimens in three analytical stages, each of which was constructed to replicate a progressively increasing degree of comminution from Stage I to Stage III.

while metapodials are meatless and thus of relatively lesser nutritional value to a forager. Thus, variable representation of bone specimens from these limb segments holds the potential to inform analysts about differential access to and use of carcasses and carcass portions by hominid foragers.

Results and Discussion

Table 2 summarizes the number of fragments identified to the correct element. The differences in proportions of skeletally identified fragments for all six elements are statistically significant in Stage II (x^2 = 15.257, 5 d.f., $p<0.01$) and III (x^2 = 11.937, 5 d.f., $p<0.05$), but not in Stage I (x^2 = 5.106, 5 d.f., $p<0.5$) or for the combined stages (x^2 = 7.736, 5 d.f., $p<0.2$). Taken together, these data seem to falsify the hypothesis that tibiae predominate in the selected Stone Age archaeofaunas (Table 1)

Table 2. Frequencies of specimens identified correctly to skeletal element[1,2]

Element	Stage I	Stage II	Stage III	Total
Humerus	8/8 (100.0%)	14/16 (87.5%)	16/32 (50.0%)	38/56 (67.9%)
Radius	8/8 (100.0%)	11/16 (68.9%)	18/32 (56.3%)	37/56 (66.1%)
Metacarpal	8/8 (100.0%)	10/16 (62.5%)	8/32 (25.0%)	26/56 (46.4%)
Femur	8/8 (100.0%)	7/16 (43.8%)	14/32 (43.8%)	29/56 (51.8%)
Tibia	7/8 (87.5%)	4/16 (25.0%)	21/32 (65.6%)	32/56 (57.1%)
Metatarsal	8/8 (100.0%)	10/16 (62.5%)	15/32 (46.9%)	33/56 (58.9%)
Total	47/48 (97.9%)	56/96 (58.3%)	92/192 (47.9%)	195/336 (58.0%)

1. *Specimens correctly identified/total number of specimens (percentage correctly identified).*
2. *See also Table 12.3 in White (1992: 293), in which total bone specimens, total number of identified specimens (NISP) and NISP as percentage of total are listed for several dozen different types of faunal assemblages. Unlike the present study, those samples include specimens other than just limb bone fragments. However, the comparative data are broadly useful, illustrating the conservative nature of most analysts; for example, of the 18 fossil and subfossil African faunas listed, NISP as percentage of total ranges from 3.9 % – 54.0 %.*

because their broken fragments are somehow more "intrinsically identifiable" than are the fragments of other limb bones. While the tibiae are the best identified in Stage III, the most "comminuted" of our stages, they are actually the least successfully identified in Stages I and II. Most telling, however, are the very close total (combined stages) frequencies for successful identification across elements. Most actual archaeofaunas preserve a wide range of limb bone fragment sizes, a condition roughly simulated by combining our discrete analytical stages (Figure 2).

If, as it seems, the predominance of tibiae in archaeofaunas is not an artifact of different identifibility potentials of limb bones, then another factor(s) must explain the phenomenon. It is true that hindlimb midshafts are, on average, denser than are those of other limb bones, at least for two medium sized artiodactyls (*Connochaetes taurinus* and *Rangifer tarandus*) whose bone mineral densities were measured using computed tomography (Lam *et al*., 1999). However, the inter-element differences in those densities are so minimal that other explanations should be explored. For example, the differential transport of carcass parts by hominids could have created the pattern of predominant hindlimb representation in the samples. This, however, seems unlikely to us because the hindlimb pattern is based on high counts of femora and especially tibiae; metatarsals are the most abundant element (based on NISP) in only two of the samples listed in Table 1. If hominids were detaching and selectively transporting hindlimbs away from carcass acquisition sites, it seems unlikely they would first go to the laborious effort of disarticulating the limb at the ankle and abandoning the metatarsal

before transport. Ethnoarchaeologically, this type of carcass segmentation and transport has not been documented often and a metatarsal contributes negligibly to the total weight of a whole articulated hindlimb.

A third possibility to explain the disjunction between our experimental results and those presented for the surveyed samples might be an artifact of the contrasting fracture patterns in the two sets of bones. A tibiae-dominated pattern might be apparent in a different experimental sample, comprised of hammerstone and carnivore broken bones. As illustrated in Figure 3, the experimental fragments used here, in their uniformity, lack the "eccentric" forms that render actual archaeofaunal specimens, by comparison, much easier to identify with confidence and accuracy using cross-sectional clues. The greater identifiability of tibiae in actual archaeofaunas might be predicated not on landmark clues, but rather on cross-sectional geometry ones, which were less apparent in the current experimental sample.

Summary and conclusion

The inclusion of limb bone shaft fragments in zooarchaeological analyses of element frequencies has been debated fiercely in recent years (e.g., Bartram & Marean, 1999; Cleghorn & Marean, in press; Marean *et al.*, 2004; Pickering *et al.*, 2003; Stiner, 1991a, 2002). We recognized a strong pattern of high hindlimb representation (especially tibiae) in our survey of analyses that included shafts in their estimates; this is the single unifying variable in the studies. The high hindlimb pattern is apparent across assemblages from disparate geographies and
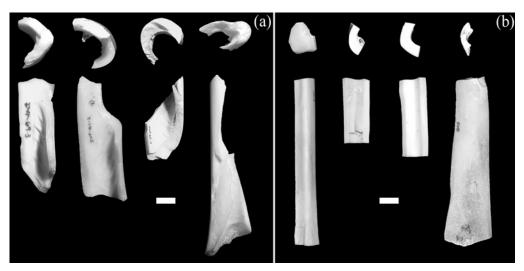

Figure 3. Comparative examples of limb bone shaft fragments created by experimental hammerstone percussion (Pickering & Egeland, in press) (a) and the experimental fragments used in this study (b). Cross-sections are illustrated above the medullary or cortical view of each fragment. Note the more "eccentric" shapes of the specimens in the former group, including especially their more complete circumferences than those of the latter group.

time periods, and different hominid species are responsible for the formation of the archaeofaunas in question. Appeals to inter-element differences in bone mineral density and carcass transport behavior by hominids are unsatisfactory explanations for the pattern. In addition, data presented here do not support a hypothesis of inter-element variance in identifiability as a reason for it. However, the fragments utilized in our experiments have limited cross-sections—all preserve <50 % of their original diaphyseal circumferences—while the fossil faunas that display the high hindlimb pattern contain many specimens with more complete circumferences. We believe this highlights the importance of cross-sectional geometry as a major tool in the accurate identification of limb bone fragments, so much so that a pattern of inter-element non-equivalence appears in the survey of fossil faunas. Although anatomical landmarks are also important tools in bone identification, our data suggest that they may not be the most important; many limb bone shaft fragments lack anatomical landmarks in large faunal samples. Support for this idea is found in various bone coding systems, in which tibiae, the best represented of limb elements in the surveyed samples, have fewer analytically utilized landmarks than do other limb bones (except for metapodials) (e.g., Morlan, 1994; Stiner, 2002). This study demonstrates that it is possible to productively explore broad patterns in zooarchaeological data at the analytical level and urges for additional work on such topics.

Acknowledgements

References

Assefa, Z. (2002). *Investigations of faunal remains from Porc-Epic: A Middle Stone Age site from southwestern Ethiopia*. Ph.D. dissertation. State University of New York at Stony Brook.

Barba, R. & Domínguez-Rodrigo, M. (2005). The taphonomic relevance of the analysis of bovid long limb bone shaft features and their application to element identification: study of bone thickness and morphology of the medullary cavity. *Journal of Taphonomy,* 3: 29-42.

Bartram, L.E. (1993). *An ethnoarchaeological analysis of Kua San (Botswana) bone food refuse*. Ph.D. dissertation. University of Wisconsin-Madison.

Bartram, L.E. & Marean, C.W. (1999). Explaining the "Klasies Pattern": Kua ethnoarchaeology, the Die Kelders Middle Stone Age archaeofauna, long bone fragmentation and carnivore ravaging. *Journal of Archaeological Science,* 26: 9-29.

Binford, L.R. (1978). *Nunamiut ethnoarchaeology*. New York: Academic Press.

Binford, L.R. (1981). *Bones: ancient men and modern myths*. New York: Academic Press.

Binford, L.R. (1984). *Faunal remains from Klasies River Mouth*. Orlando (FL): Academic Press.

Brain, C.K. (1981). *The hunters or the hunted? An introduction to African cave taphonomy*. Chicago: University of Chicago Press.

Bunn, H.T. (1982). *Meat-eating and human evolution: Studies on the diet and subsistence patterns of Plio-Pleistocene hominids in East Africa*. Ph.D. dissertation. University of California, Berkeley.

Bunn, H.T. (1983). Comparative analysis of modern bone assemblages from a San hunter-gatherer camp in the Kalahari Desert, Bostwana, and from a spotted hyena den near Nairobi, Kenya. In (Clutton-Brock, J. & Grigson, C., Eds.) *Animals and archaeology: Vol. 1, Hunters and their prey*, pp. 143-148. British Archaeological Reports International Series 163.

Bunn, H.T. (1986). Patterns of skeletal part representation and hominid subsistence activities at Olduvai Gorge, Tanzania, and Koobi Fora, Kenya. *Journal of Human Evolution,* 15: 673-690.

Bunn, H.T. (1991). A taphonomic perspective on the archaeology of human origins. *Annual Review of Anthropology,* 20: 433-467.

Bunn, H.T. & Kroll, E.M. (1986). Systematic butchery by Plio-Pleistocene hominids at Olduvai Gorge, Tanzania. *Current Anthropology,* 27: 431-452.

Cleghorn, N. & Marean, C.W. (in press). The destruction of skeletal elements by carnivores: the growth of a general model for skeletal element destruction and survival in zooarchaeological assemblages. In (Pickering, T.R., Schick, K. & Toth, N., Eds.) *African taphonomy: A tribute to the career of C.K. "Bob" Brain*. Bloomington (IN): Stone Age Institute Press.

Domínguez-Rodrigo, M. (1999). Meat-eating and carcass procurement at the FLK *Zinj* 22 site, Olduvai Gorge (Tanzania): a new experimental approach to the old hunting-versus-scavenging debate. In (Ullrich, H., Ed.) *Lifestyles and survival strategies in Pliocene and Pleistocene hominids*, pp. 89-111. Schwelm: Edition Archaea.

Hill, M.G. (2001). *Paleoindian diet and subsistence behavior on the Northwestern Great Plains of North America*. Ph.D. dissertation. University of Wisconsin-Madison.

Klein, R.G. (1976). The mammalian fauna of the Klasies River Mouth sites, southern Cape Province, South Africa. *South African Archaeological Bulletin,* 31: 75-98.

Klein, R.G. & Cruz-Uribe, K. (1984). *The analysis of animal bones from archaeological sites.* Chicago: University of Chicago Press.

Klein, R.G., Cruz-Uribe, K. & Milo, R.G. (1999). Skeletal part representation in archaeofaunas: comments on "Explaining the 'Klasies Pattern': Kua Ethnoarchaeology, the Die Kelders Middle Stone Age archaeofauna, long bone fragmentation and carnivore ravaging" by Bartram & Marean. *Journal of Archaeological Science,* 26: 1225-1234.

Lam, Y., Chen, X. & Pearson, O.M. (1999). Intertaxonomic variability in patterns of bone denisty and the differential representation of bovid, cervid, and equid elements in the archaeological record. *American Antiquity,* 64: 343-362.

Marean, C.W. (1998). A critique of the evidence for scavenging by Neanderthals and early modernhumans: New data from Kobeh Cave (Zagros Mountains) and Die Kelders (South Africa Middle Stone Age). *Journal of Human Evolution,* 35: 111-136.

Marean, C.W. & Cleghorn, N. (2003). Large mammal skeletal element transport: applying foraging theory in a complex taphonomic system. *Journal of Taphonomy* 1: 15-42.

Marean, C.W. & Kim, S.Y. (1998). Mousterian large mammal remains from Kobeh Cave: Behavioral implications for Neanderthals and early modern humans. *Current Anthropology (Supplement),* 39: S79-S113.

Marean, C.W. & Spencer, L.M. (1991). Impact of carnivore ravaging on zooarchaeological measures of element abundance. *American Antiquity,* 56: 645-658.

Marean, C.W., Abe, Y., Nilssen, P.J. & Stone, E.C. (2001). Estimating the minimum number of skeletal elements (MNE) in zooarchaeology: a review and a new image-analysis GIS approach. *American Antiquity,* 66: 333-348.

Marean, C.W., Domínguez-Rodrigo, M. & Pickering, T.R. (2004). Skeletal element equifinality in zooarchaeology begins with method: the evolution and status of the "shaft critique". *Journal of Taphonomy*, 2: 69-98.

Marean, C.W., Spencer, L.M., Blumenschine, R.J. & Capaldo, S.D. (1992). Captive hyaena bone choice and destruction, the schlepp effect and Olduvai archaeofaunas. *Journal of Archaeological Science,* 19: 101-121.

Monahan, C.M. (1996). New zooarchaeological data from Bed II, Olduvai Gorge, Tanzania: implications for hominid behavior in the Early Pleistocene. *Journal of Human Evolution*, 31: 93-128.

Morlan, R.E. (1994). Bison bone fragmentation and survivorship: a comparative method. *Journal of Archaeological Science,* 21: 797-807.

Münzel, S. (1986). Coding system for bone fragments. In (van Wijngaarden-Bakker, L.H., Ed.) *Database management and zooarchaeology*, pp. 193-195. PACT 14.

Outram, A.K. (2001). A new approach to identifying bone marrow and grease exploitation: why the "indeterminant" fragments should not be ignored. *Journal of Archaeological Science,* 28: 401-410.

Perkins, D. & Daly, P. (1968). A hunter's village in Neolithic Turkey. *Scientific American,* 219: 96-106.

Pickering, T.R. (1999). *Taphonomic interpretations of the Sterkfontein early hominid site (Gauteng, South Africa) reconsidered in light of recent evidence.* Ph.D. dissertation. University of Wisconsin-Madison.

Pickering, T.R. & Egeland, C.P. (in press). Experimental patterns of hammerstone percussion damage on bones: Implications for inferences of carcass processing by humans. *Journal of Archaeological Science.*

Pickering, T.R., Domínguez-Rodrigo, M., Egeland, C.P. & Brain, C.K. (in press). Carcass foraging by early hominids at Swartkrans Cave (South Africa): A new investigation of the zooarchaeology and taphonomy of Member 3. In (Pickering, T.R., Schick, K. & Toth, N., Eds.) *African taphonomy: A tribute to the career of C.K. "Bob" Brain.* Bloomington (IN): Stone Age Institute Press.

Pickering, T.R., Domínguez-Rodrigo, M., Egeland, C.P. & Brain, C.K. (2005). The earliest evidence of hominid butchery in southern Africa: new zooarchaeological and taphonomic data on the use of large animal carcasses at Swartkrans Members 1 – 3.

Paper presented at the *XIVth Annual Meeting of the Paleoanthropology Society*, held in Milwaukee, Wisconsin, April 4-6, 2005.

Pickering, T.R., Marean, C.W. & Domínguez-Rodrigo, M. (2003). Importance of limb bone shafts in zooarchaeology: a response to "On *in situ* attrition and vertebrate body part profiles" (2002), by M.C. Stiner. *Journal of Archaeological Science,* 30: 1469-1482.

Rapson, D.J. (1990). *Pattern and process in intrasite spatial analysis: Site structural and faunal research at the Bugas-Holding site.* Ph.D. dissertation. University of New Mexico.

Stiner, M.C. (1991a). Food procurement and transport by human and non-human predators. *Journal of Archaeological Science,* 18: 455-482.

Stiner, M.C. (1991b). The faunal remains from Grotta Guattari: A taphonomic perspective. *Current Anthropology,* 32: 103-117.

Stiner, M.C. (1991c). An interspecific perspective on the emergence of the modern human predatory niche. In (Stiner, M.C., Ed.) *Human predators and prey mortality*, pp. 149-185. Boulder (CO): West View Press.

Stiner, M.C. (1994). *Honor among thieves: A zooarchaeological study of Neandertal ecology.* Princeton: Princeton University Press.

Stiner, M.C. (2002). On *in situ* attrition and vertebrate body part profiles. *Journal of Archaeological Science,* 29: 979-991.

Turner, A. (1989). Sample selection, schlepp effects and scavenging: The implications of partial recovery for interpretations of the terrestrial mammal assemblage from Klasies River Mouth. *Journal of Archaeological Science,* 16: 1-11.

White, T.D. (1992). *Prehistoric cannibalism at Mancos 5MTUMR-2346*. Princeton: Princeton University.