

Long Bone Fragmentation and Interpretation of Faunal Assemblages: Approaches to Comparative Analysis

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Fragmentation of archaeological faunal assemblages has served as the basis for inferring a wide range of human behaviours. However, relationships between long bone breakage and past behaviours have often been expressed in terms of a direct equivalence between bone breakage and intensity of processing—that is, the greater the fragmentation, the more intense the processing. More refined interpretations based on bone breakage require a development of techniques to examine variability within the archaeological record. Data from western North American archaeological sites and several recent Alaskan collections are used as the basis for documentation of assemblage variability in terms of (1) frequencies of complete bones; (2) percentage difference values of proximal and distal articular ends; (3) length of shaft attached to articular ends; and (4) use of ratios of articular ends to shaft splinters and long bone shaft fragments in the development of minimum number of elements counts.

Keywords: NORTH AMERICA, FAUNAL ANALYSIS, BUTCHERY, TAPHONOMY, BISON, BIGHORN SHEEP, BONE BREAKAGE.

Introduction

Over the last 30 years, documentation of skeletal element frequencies has become a hallmark of archaeological faunal studies in western North America (e.g. White, 1953, 1954, 1955; Kehoe & Kehoe, 1960; Kehoe, 1967; Frison, 1970, 1973, 1974; Wheat, 1972, 1979; Speth & Parry, 1978, 1980; Speth, 1983; Frison & Todd, 1986, 1987). This growing body of data provides a basis for development of more refined interpretations of both past behaviours and post-occupational processes that have played a part in the formation of archaeological faunal assemblages. While there is still much to be learned from investigation of these bone counts, documentation and comparative analysis of several additional classes of information such as skeletal disarticulation, intra-site spatial patterning, and a more detailed and systematic consideration of the nature of long bone fragmentation or destruction have interpretative potential not provided by element frequencies alone.

Among the most common techniques currently used in the quantification of faunal assemblages are summaries on minimum number of identified specimens (NISP), the

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minimum number of skeletal elements (MNE) and the minimum number of individuals (MNI). The statistical and methodological shortcomings of these closely related techniques as they affect interpretation of faunal assemblages have been reviewed in a number of publications (Chaplin, 1971; Grayson, 1984; Klein & Cruz-Uribe, 1984; Lyman, 1985). The quantification of fragmentary specimens has consistently been identified as a problem in the development of MNE and MNI values, and the lack of consistent treatment of fragmentary remains represents a significant source of discussion among faunal analysts (e.g. Chaplin, 1971: 64–67; Binford, 1978, 1981, 1984; Brain, 1981; Bunn, 1982, 1983, 1985; Speth, 1983; Thomas & Mayer, 1983; Klein & Cruz-Uribe, 1984; Bunn & Kroll, 1986). While several researchers (e.g. Biddick & Tomenchuck, 1975; Sadek-Kooros, 1972, 1975) have discussed techniques for a description of specific fracture morphologies, there has been little emphasis on the inter-assemblage comparison of fracture patterns.

This paper examines several techniques for the comparison of breakage morphologies and fragmentary bones in relation to element frequency data from archaeological sites. Long bone fragmentation can be used as the basis for inter-assemblage analyses in several ways. These include, but are not restricted to, the following: tabulation of breakage type frequencies by element [such as a distinction between dry versus green bone fractures (Todd & Stanford, 1987)]; morphology of bone fragments, including frequencies of diagnostic long bone shaft fragments, which often provide markedly different minimum number of element counts when compared with the values for the adjacent articular ends (Bunn, 1982, 1983, 1985; McKee, 1986; Todd *et al.*, 1985); ratio of articular ends to shaft splinters (Binford, 1981: 175–177); percentage of complete bones or a ratio of complete to incomplete bones within an assemblage; differences in percentage representation of proximal and distal articular ends (Richardson, 1980); and amount of shaft remaining attached to articular ends of incomplete bones (Binford, 1981). Analysis incorporating the first approach has been discussed elsewhere (Todd & Stanford, 1987). In this paper, we emphasize techniques for comparing: (1) the percentage of complete bones, (2) the percentage difference in representation of proximal and distal articular ends, (3) the amount of shaft remaining attached to articular ends, and (4) shaft fragment counts and their relationships to articular end frequencies.

In the following illustrations of comparative techniques, we use a series of assemblages that have been subjected to a variety of forms of modification. The comparative techniques described are directed toward recognition of inter-site bone fragmentation patterns. In this paper, we emphasize techniques for improved documentation of the range of variability in archaeological settings. This approach does not, in itself, provide an explanation of the processes responsible for the patterning. Rather, the techniques are designed to aid in the recognition of broader sets of inter-assemblage structure in need of explanation. Pattern recognition studies, such as those outlined below or discussed by Bunn (1983), are a fundamental step toward implementation of additional research to assign meaning.

Percentage Complete

Several of the techniques discussed here use basic skeletal element count data from published or previously analysed sites as a starting point (Tables 1 & 2). Processes that result in differential element destruction and/or removal, regardless of the agents responsible, result in lower percentages of complete elements within an assemblage. These processes can include either pre-depositional forces or post-depositional diagenesis.

Assessing relationships between assemblages based on completeness values can be a straight forward exercise, such as the plot comparing percentage complete values of the major limb bones from the Casper (Frison, 1974) and Jones-Miller (Stanford, 1974, 1978, 1979, 1984) Hell Gap bison bone beds [Figure 1(a)]. Although there are a number of differences in the nature of the bone beds at these sites with many of the elements from

Table 1. Jones-Miller bison long bone fragmentation summary

Element	No. complete (1)	Fragments (2)	Proximal (3)	Distal (4)	Max. (5) ^a	% Complete (6) ^b	% Difference (7) ^c
Humerus	53	374	35	253*	306	17.32	55.33
Radius	198	193	117*	112	315	62.89	0.80
Metacarpal	203	41	60	76*	279	72.76	2.95
Femur	32	431	156*	112	188	17.02	13.25
Tibia	64	537	118	218*	282	22.70	21.55
Metatarsal	152	94	121	125*	277	54.87	0.73

^aMaximum element count, complete plus the greater of proximal or distal ends (maximum marked with asterisk in columns 3-4).

^bPercentage of elements complete = $\frac{\text{Col. 5}}{\text{Col. 1} \times 100}$.

^cPercentage difference, between counts of proximal and distal ends (from Richardson, 1980):

$$\frac{|([\text{Col. 1} + \text{col. 3}] - [\text{col. 1} + \text{col. 4}]) \times 100|}{(\text{Col. 1} + \text{col. 3}) + (\text{col. 1} + \text{col. 4})}$$

Casper recovered as complete bones included in articulated units and most of the Jones-Miller bones being scattered, fragmented (often with dry-bone fractures) individual elements, the *general structure* of limb bone fragmentation is remarkably similar. Metapodials are the most common complete bones and humeri are the most fragmented elements in both sites.

An important point to be considered in the study of long bone completeness is the difference between simple *in situ* fractures and fractures associated with deletion of bone portions. If only percentage complete values are examined, it is not possible to distinguish between assemblages where bones have been broken with the component parts remaining at the site and assemblages where incomplete elements are the result of destruction or removal of parts of the bones (see Lyman, 1985) during any phase of the formational history of a deposit. Destruction of articular ends by carnivores, intensive processing by humans (such as bone grease manufacture), or post-occupational mechanical or chemical modifications can result in systematic, patterned destruction of bone portions (Binford & Bertram, 1977). Clearly, investigation of fragmentation requires techniques for investigating differences between such assemblages in addition to simple comparison of percentage complete values.

Percentage Difference in Articular Ends

A second measure of long bone fragmentation, which can be useful in recognizing patterns of differential destruction of articular ends, is the percentage difference between representation of proximal and distal articular ends as developed by Richardson (1980) in a study of bone modification by African predator/scavengers. The percentage difference value provides a technique to identify elements that have had one end preferentially destroyed or removed (Table 1). Bones that have been subjected to the most severe destruction or segment removal will have a large percentage difference value. Even if all elements of a given type on a site have been broken, either during an occupation or post-depositionally, but isolated proximal and distal ends are present in similar proportions, percentage values will be low.

As an illustration of this point, fragmentation data from several Palaeo-Indian period bison bone beds—Horner II (Todd, 1987c), Lamb Spring (McCartney, 1984), Casper

Table 2. Long bone fragmentation summaries from several Palaeo-Indian bison bone beds and caribou data from Alaskan wolf kills (calculations as in Table 1)

Element(a)	Jones-Miller		Horner II		Casper		Olsen-Chubbuck		Lamb Spring		Wolf kills	
	% Comp.	% Diff.	% Comp.	% Diff.	% Comp.	% Diff.	% Comp.	% Diff.	% Comp.	% Diff.	% Comp.	% Diff.
Humerus	17.32	55.33	46.40	40.98	34.74	40.74	85.96	1.42	5.88	54.55	10.00	60.00
Radius	62.89	0.80	56.60	22.61	72.46	1.47	82.32	5.54	57.14	16.67	25.00	23.08
Metacarpal	72.76	2.95	96.52	1.77	98.78	0.61	—	—	100.00	0.00	45.45	0.00
Femur	17.02	13.25	42.67	12.78	53.70	4.00	81.71	3.55	20.00	0.00	12.50	39.13
Tibia	22.70	21.55	58.97	17.29	57.14	12.50	80.68	2.04	58.82	17.24	27.27	37.50
Metatarsal	54.87	0.73	91.27	1.20	87.27	0.92	—	—	52.94	13.33	35.29	30.77

% Comp., percentage of complete elements. % Diff., percentage difference of proximal and distal articular ends.

References: Jones-Miller: Todd, 1987a; Horner II: Todd, 1987c; Olsen-Chubbuck: Wheat, 1972; Lamb Spring: McCartney, 1984; wolf kills: Binford, 1981: table 4-07.

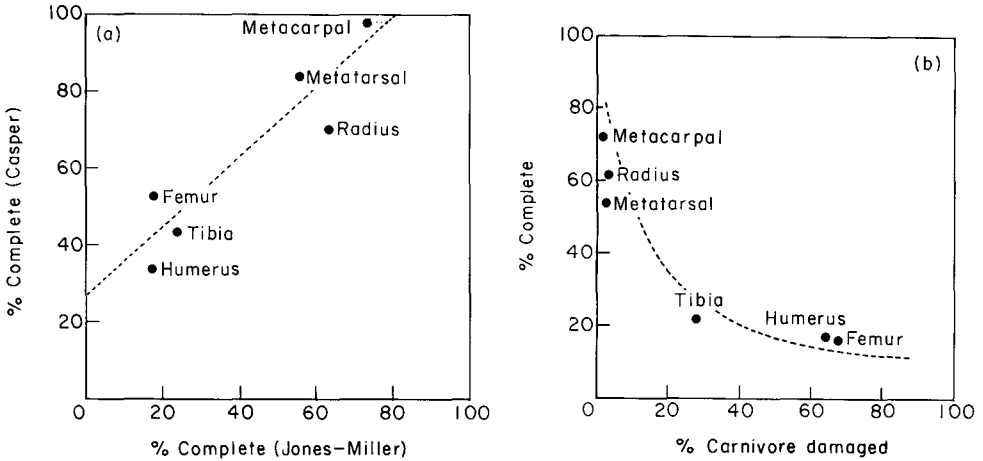


Figure 1. Relationships between percentages of complete bones from the Jones-Miller and Casper bison bone beds (a), and between fragmentation (% complete) and carnivore damage (b) to the Jones-Miller bones (from Todd, 1987a).

(Frison, 1974), Jones-Miller (Todd, 1987a)—and a group of caribou bone assemblages from recent Alaskan wolf kills reported by Binford (1981: table 4.07) are summarized in Table 2. The general pattern is similar for all assemblages. Fragmentation of forelimbs decreases from the humerus down through the metacarpal [Figure 2(a)]. The bison kills, with a greater number of complete bones, form a group that differs slightly from the wolf kills.

For these assemblages, the percentage difference values for the articular ends of the forelimb bones decrease from proximal to distal [Figure 2(b)]. There are large differences for the articular ends of the humeri, less for the radii, and almost no difference in the articular end values of the metacarpals (Table 2).

There is also a tendency for fragmentation of the rear limb to decrease distally [Figure 2(c)]. In general, the percentage differences between articular ends of the femur and metatarsal are low, while percentage difference values for the tibiae are moderate [Figure 2(d)]. Again, the overall pattern for rear limb bones is similar for the bison and wolf kill assemblages with the primary differences being greater fragmentation and destruction at the wolf kills.

Several lines of evidence suggest that carnivore modification has been an important factor in the formation of these bison bone beds (Todd, 1983, 1987a,c). For example, patterning in frequencies of broken bones and numbers of elements with definite carnivore modification indicates that fragmentation and gnawing may be related [Figure 1(b)]. Clearly, bone breakage is not the exclusive domain of humans and is not a direct reflection of intensity of processing. Before statements about the relationships between fragmentation and human subsistence strategies can be advanced, the role of several non-cultural processes needs to be evaluated.

One technique for estimating the degree of carnivore modification to faunal assemblages is based on a pattern of differential destruction of the articular ends of the humerus and tibia (Binford, 1981: figures 5.07–5.08; see also Haynes, 1980a,b; Brain, 1981). Both elements have marked differences in survival potential and are also among the most commonly damaged by gnawing. Binford (1981) has suggested that plots of proximal end values against distal end values for the humerus and tibia provide an indication of the

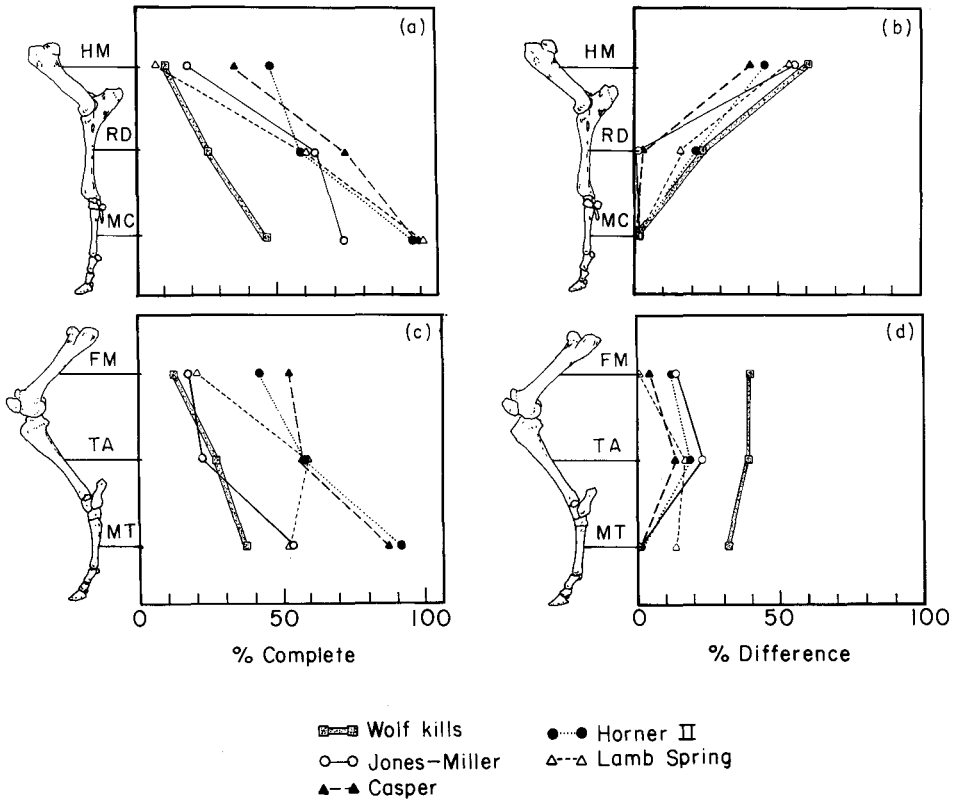


Figure 2. Comparisons of forelimb [(a)–(b)] and rear limb [(c)–(d)] bone fragmentation among Palaeo-Indian bison bone beds and Alaskan wolf kills.

intensity of damage. Assemblages with large numbers of distal ends and few proximal ends fall into a “zone of destruction”. Those with a more even representation of the two ends have been subjected to less gnawing.

The use of percentage difference values for articular ends allows the degree of damage to both humerus and tibia to be compared on a single plot (Figure 3). This technique has the advantage of providing a more complete picture of the general nature of damage than the individual element plots used in Binford’s study. Plots of percentage difference values for several Plains sites as well as the aggregated wolf kill sample mentioned earlier illustrate several significant relationships (Figure 3). The Olsen-Chubbuck kill-butchery site (Wheat, 1972), where most bones were found tightly packed within a narrow arroyo, shows almost equal numbers of proximal and distal ends for both elements. This indicates limited carnivore destruction, probably linked to limited access by carnivores to the majority of bones contained within the arroyo. Other bison kill sites exhibit increasing difference values of proximal and distal ends. This may reflect increasing intensity of carnivore damage to the bones. Additional lines of evidence, such as percentages of definitely gnawed bones within the sites, and relationships between bone completeness and percentages of elements with evidence of carnivore damage, tend to support the general ordering of the kill site assemblages as shown here. The wolf kill assemblages, where modification is definitely the result of carnivore modification, fall on the same curve but with indications of more severe damage than at any of the bison kill sites.

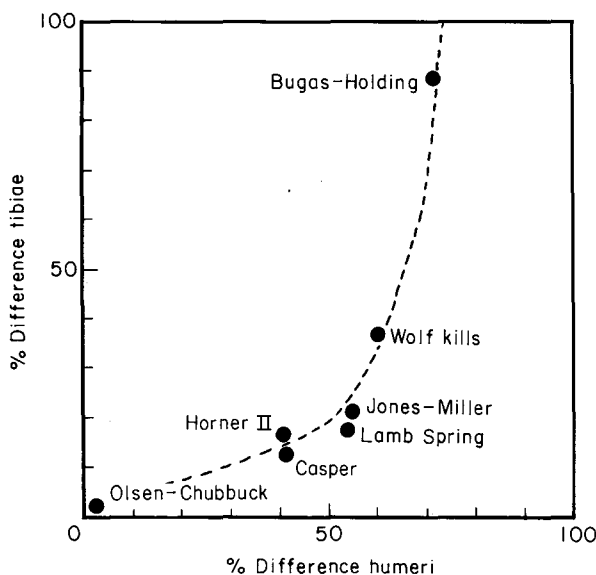


Figure 3. Percentage difference values for long bone articular ends. Except for the wolf kills, which are caribou bones, values for all sites are for bison.

In terms of the study of long bone fragmentation, such simple procedures hold promise not only for comparison of assemblages, but also for recognition of a variety of the agents responsible for patterns of bone modification. However, at this point, it must be kept in mind that this approach is merely *documenting patterns of differential destruction and not directly indicating processes responsible for the observed differences*. A number of processes, including deliberate fractures for marrow removal and smashing of articular ends for extraction of bone grease by humans, or post-depositional chemical deterioration can also result in patterned destruction of the low density, high grease content components of an assemblage.

Evidence from Bugas-Holding, a Late Prehistoric Period occupation site, suggests that processing bone as part of the food production system was being carried out during the course of a 3–4-month long winter occupation (Todd *et al.*, 1985; Rapson & Todd, 1987). Bone is unweathered or minimally weathered, and there is little indication of post-depositional deterioration. Based on the relationships between percentage difference values of humerus and tibia articular ends (Figure 3), the Bugas-Holding site exhibits the most extreme destruction of articular ends of any of the assemblages discussed here (Tables 3 & 4). The bones from this site, which include nearly equal numbers of bison (*Bison bison bison*; MNI=15) and mountain sheep (*Ovis canadensis*; MNI=14), are closely associated with a series of hearths (Figure 4) and are highly fragmented with no complete limb bones having been recovered. Both species have a high frequency of cut-marks, and many fragments exhibit single points of impact. The extremely well-preserved bones at Bugas-Holding, while showing occasional indications of limited carnivore damage, do not exhibit the high frequency of characteristic tooth marks or furrows expected on heavily carnivore-modified bones. In addition, there is a marked difference in the types of distal end segments represented at Bugas-Holding compared to those usually created by carnivore modification. For example, typical carnivore damage to the humerus, and presumably most forms of post-depositional deterioration, usually results in removal of only the thin-walled proximal portions of the shaft and seldom produces

Table 3. Long bone fragmentation summaries of bison and bighorn sheep from the Bugas-Holding site

Element	Bison		Bighorn sheep	
	% Comp.	% Diff.	% Comp.	% Diff.
Humerus	0.00	83.33	0.00	86.67
Radius	0.00	28.00	0.00	9.68
Metacarpal	0.00	50.00	0.00	33.33
Femur	0.00	33.33	0.00	20.00
Tibia	0.00	58.30	0.00	100.00
Metatarsal	0.00	25.00	0.00	46.67

% Comp., percentage of complete bones (see Table 1). % Diff., percentage difference between proximal and distal ends (counts from Table 4):

$$\frac{|(\text{Proximal} - \text{distal})| \times 100}{\text{Proximal} + \text{distal}}$$

destruction of the thicker-walled bone below the deltoid tuberosity (see Binford, 1981: figure 3.44). On the other hand, at Bugas-Holding all distal humeri are represented by the articular end with only limited amounts of shaft attached [Figure 5(a)–(d)]. Breakage of the thick-walled bone near the distal end seems to be the result of a different process of destruction than that indicated by the removal of the relatively light-weight shaft portions nearer the proximal end.

Shaft Length Ratio

This suggests another technique for investigation of fragmentation, based on the amount of shaft attached to articular ends. While descriptive codes based on the amount of shaft have been developed and used (Binford, 1981: 171–177; Bunn, 1983), the nature of such descriptive categories often makes inter-assemblage comparisons difficult. The general relationship between the amount of shaft attached to articular ends in assemblages having suffered moderate carnivore damage [as opposed to more extreme damage, such as occurs at dens (see Klein & Cruz-Urbe, 1984; table 5.2)] has been summarized as follows:

... high frequencies of articular ends with attached shafts and shanks are characteristic of animal-gnawed assemblages. Isolated articular ends may occur in both types of assemblages [i.e. animal gnawed and marrow fractured] but are largely the exclusive or dominant forms in assemblages cracked for marrow by man (Binford, 1981: 173).

In order to refine this observation as a more generally applicable analytical technique, we have adopted a simple solution for conducting assemblage comparisons based on measurements of shaft fragment lengths in relation to dimensions of the attached articular ends (Figure 6). One difficulty with direct comparison of shaft lengths, especially in a highly sexually dimorphic species such as bison, is that an articular end with 15 cm of attached shaft from a large male represents breakage at a different anatomical position (closer to the articular end) than an element from a small female having exactly the same length of shaft.

To alleviate this problem, shaft to articular end proportions are compared using articular end measurements to develop a ratio value (Figure 6). This eliminates the sexual size difference problem. For bison humeri, complete elements (regardless of sex) have ratio

Table 4. Comparison of long bone portions of bison (*Bison bison*) with those of bighorn sheep (*Ovis canadensis*) from the Bugas-Holding site

Element, portion	Bison ^a			Bighorn sheep ^a		
	MNE	MAU	MAU%	MNE	MAU	MAU%
Humerus, proximal	1	0.5	5.26	1	0.5	5.00
Humerus, deltoid tuberosity	12	6.0	63.16	8	4.0	40.00
Humerus, teres major tub.	10	5.0	52.63	13	6.5	65.00
Humerus, posterolateral foramen	8	4.0	42.11	19	9.5	95.00
Humerus, proximal olecranon fossa	14	7.0	73.68	17	8.0	85.00
Humerus, distal	11	5.5	57.89	14	7.0	70.00
Radius, proximal	15	7.5	78.95	17	8.5	85.00
Radius, posterolateral foramen	15	7.5	78.95	8	4.0	40.00
Radius, radial tuberosity	15	7.5	78.95	15	7.5	75.00
Radius, distal	9	4.5	47.37	14	7.0	70.00
Ulna, olecranon	4	2.0	21.05	2	1.0	10.00
Ulna, anconeal	13	6.5	68.42	14	7.0	70.00
Ulna, shaft	11	5.5	57.89	15	7.5	75.00
Ulna, styloid	9	4.5	47.37	11	5.5	55.00
Metacarpal, proximal	4	2.0	21.05	14	7.0	70.00
Metacarpal, distal	12	6.0	63.16	7	3.5	35.00
Femur, proximal	4	2.0	21.05	3	1.5	15.00
Femur, minor trochanter	7	3.5	36.84	9	4.5	45.00
Femur, supracondyloid fossa	12	6.0	63.16	2	1.0	10.00
Femur, distal	8	4.0	42.11	2	1.0	10.00
Tibia, proximal	5	2.5	26.32	1	0.5	5.00
Tibia, posterolateral foramen	12	6.0	63.16	18	9.0	90.00
Tibia, anterior crest	13	6.5	68.42	19	9.5	95.00
Tibia, distal	19	9.5	100.00	9	4.5	45.00
Metatarsal, proximal	5	2.5	26.32	11	5.5	55.00
Metatarsal, distal	3	1.5	15.79	4	2.0	20.00

^aStandardized MAU values (MAU%) are based on the total assemblages, not just the elements listed in this table.

values slightly greater than 4.0. The distal margin of the deltoid tuberosity is always located at a ratio value near 2.3. In other species, such as bighorn sheep illustrated in Figure 6, differences in element proportions result in differences in absolute ratio values with the value for complete sheep humeri at approximately 5.0. Nevertheless, the sheep bones exhibit an internally consistent relationship between element morphology and shaft ratio comparable to the bison.

Initial comparisons based on shaft ratio values provide interesting results. At the Horner II bison bone bed [Figure 7(a)], there is a high percentage of complete bones and a moderate number of distal ends with attached shafts that have definite tooth marks and furrowing indicating carnivore modification. Ratio values reflect this pattern with all the carnivore damaged bones displaying values greater than 2.5. The assemblage from the Finley bison bone bed [Figure 7(b)] is composed of bones that have suffered a good deal of recent fracture of presumably nearly complete bones by looters prior to the collection of

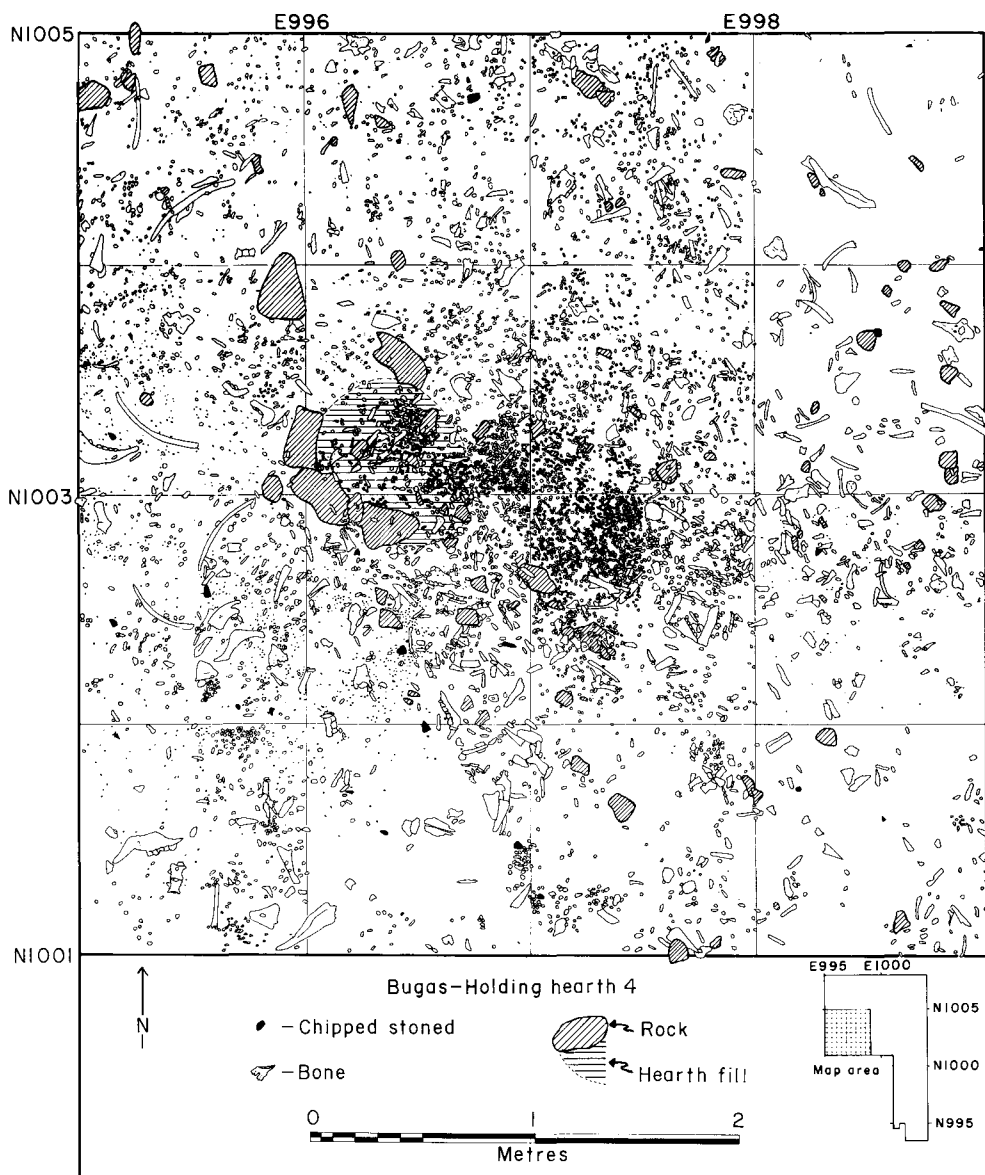


Figure 4. Relationships of faunal remains and chipped stone to hearth 4 at the Bugas-Holding site.

the bones by the University of Wyoming (Haspel & Frison, 1987). The Finley sample, which represents bones fractured predominately as a result of recent disturbance rather than prehistoric actions and represents a markedly different formational history than the other assemblages, exhibits breakage near the thin-walled proximal end similar to that of carnivore-modified bones.

At the Bugas-Holding site, a different process of proximal end destruction is suggested—marrow fracturing followed by bone grease processing. All distal bison humeri have shaft ratio values of less than 2.5 and most have values less than 2.0 [Figure 7(c)]. The use of ratio

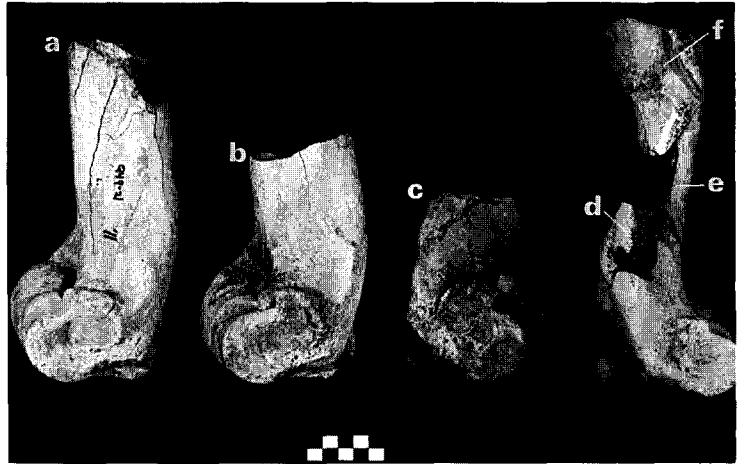


Figure 5. Distal bison humeri [(a)–(d)] from the Bugas-Holding site and conjoined shaft fragments [(e), (f)].

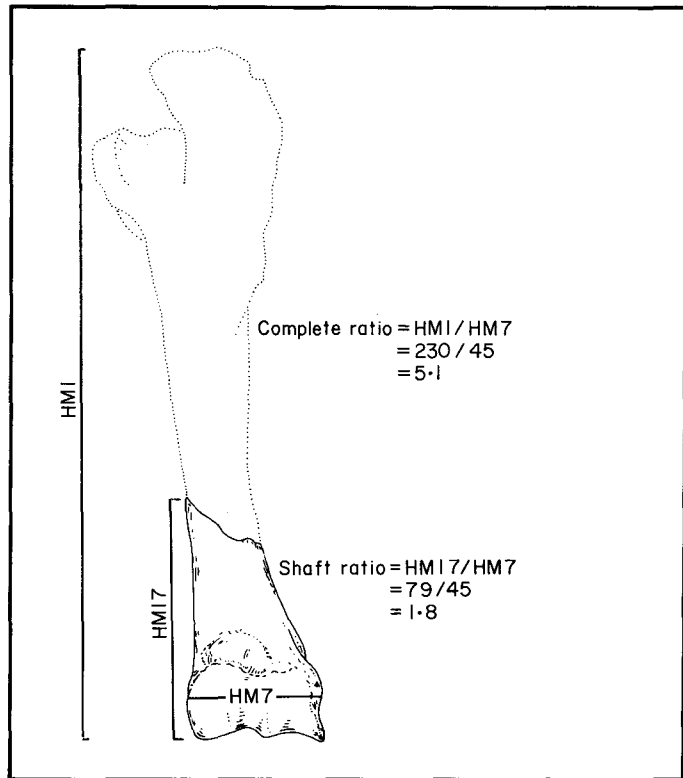


Figure 6. Measurements used to calculate shaft ratio for distal humeri (measurements described by Todd, 1987b).

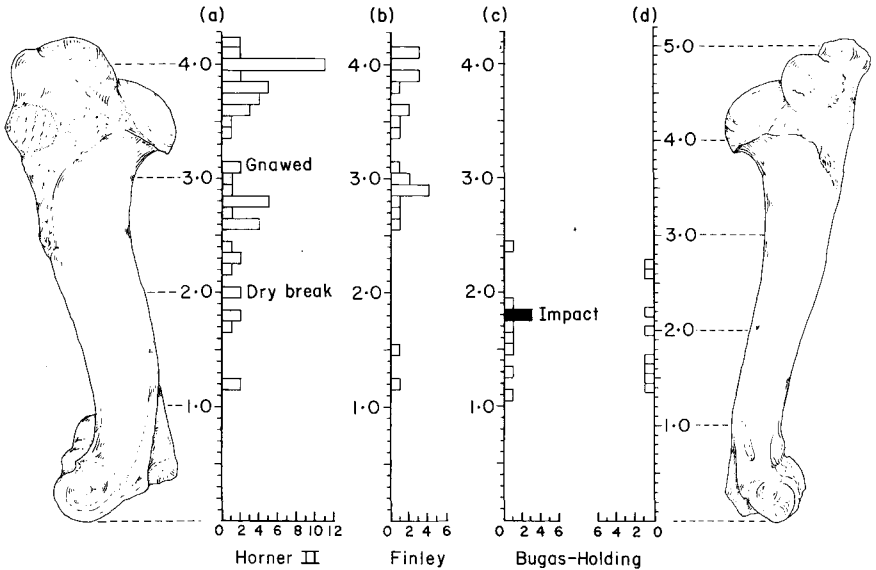


Figure 7. Shaft ratios for bison humeri from (a) the Horner II bone bed (with the specimens having carnivore damage indicated), (b) the Finley bone bed, (c) the Bugas-Holding site (with specimens having impact points indicated), and (d) the mountain sheep humeri from Bugas-Holding.

values provides a simple comparative technique to aid in discriminating among several patterns of element breakage that can not be provided by tabulation of element counts alone.

An important extension of the use of shaft ratio values is their utility is allowing inter-species comparisons of bone breakage. While difference in limb bone proportion means that the absolute ratio values will differ by species, all such values can be scaled for comparison. As illustrated with the bison assemblages [Figure 7(a)–(c)] and bighorn sheep [Figure 7(d)] from Bugas-Holding, the scales can be standardized so that analogous anatomical portions are associated with similar positions on the scales. In the example presented here, the sheep humeri from Bugas-Holding are consistently represented by distal articular ends with little attached shaft. This pattern is more similar to the bison from the same site than to bison from other sites subjected to different types of proximal end destruction.

It could be argued that the variation in bone size and long bone shaft thickness might lead to different patterns of shaft destruction for the smaller body-sized sheep in comparison to bison. However, available data indicate that this is not the case and that inter-species comparisons may point to similar processes of modification. As an illustration of this point, ratio values for the Bugas-Holding site bison are compared to similar values developed for an assemblage of caribou bones (Figure 8) collected at the Palangana site as part of Binford's (1978) ethnoarchaeological study of the Nunamiut. In the ethnohistorically documented Palangana bones, the majority of breakage is the result of marrow fracturing with most distal fragments having less than half of the shaft attached. Structurally, the zone of breakage is the same as the primary breakage zone on the Bugas-Holding bison and mountain sheep specimens. The single humerus from the Palangana sample with tooth furrows and other definite indications of carnivore modification is more similar to the gnawed bones from the Horner bone bed [Figure 7(a)]. The patterning of

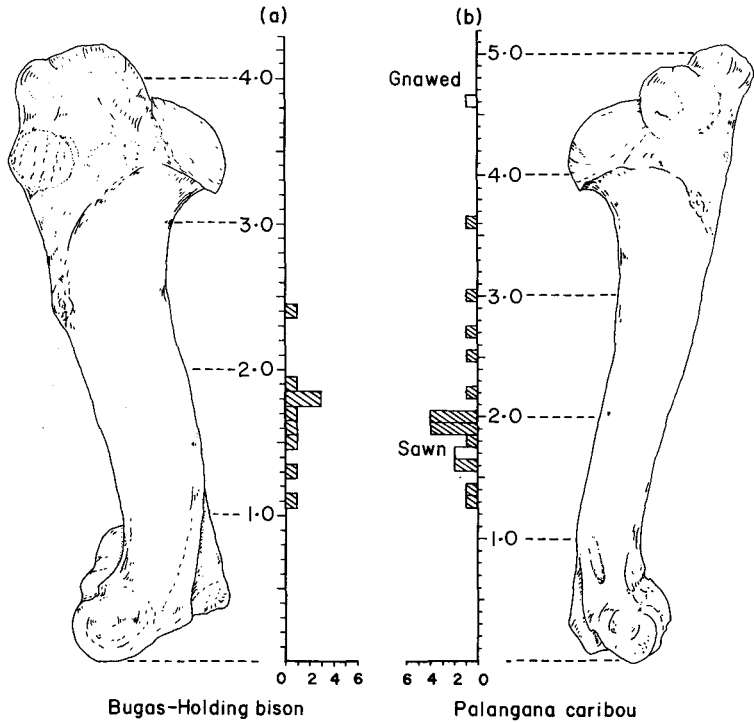


Figure 8. Histograms of distal humerus shaft ratios for (a) Bugas-Holding site bison and (b) Palangana site caribou.

breakage locations highlights structural differences between the Bugas-Holding materials and the other assemblages that were not apparent when only the percentage differences between articular ends were considered.

Shaft Fragments

The problems associated with comparative study of fragmentary bones from archaeological sites have long been recognized (Chaplin, 1971: 64–67) and continues to present analytical difficulties (Klein & Cruz-Urbe, 1984). As suggested by both Chaplin (1971) and Klein & Cruz-Urbe (1984), the most common solution is to focus on the development of MNI estimates, usually based on numbers of articular ends represented. However, especially in extensively fragmented assemblages, this approach can lead to conclusions that are based on a very small subset of the total collection.

In response to the “fragments problem”, several researchers have begun examination of fragmentation of archaeological bones in relation to frequencies of shaft fragments and articular ends. Based on a series of marrow fracturing experiments, Binford (1978: 155–157) has suggested that numbers of articular ends and long bone splinters/shaft fragments are related to the manner in which bones are broken. The regression equation developed by Binford can be used to examine the relationships between the observed numbers and expected frequencies of bone fragments as one way to estimate whether an assemblage has been subjected to articular end destruction. For an initial pattern recognition study, these relationships can be used to develop ideas about the structure of an assemblage. However, as with many of the pattern recognition techniques that provide an

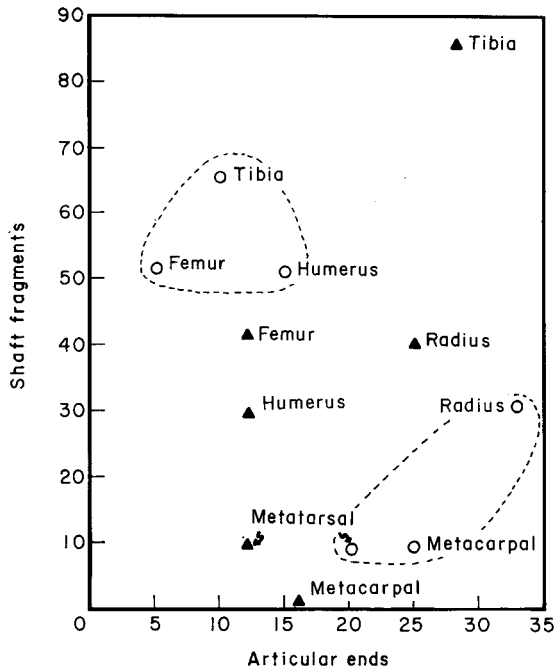


Figure 9. Relationship between articular end and shaft fragment frequencies of bison and bighorn sheep from the Bugas-Holding site. ▲, Bison; ○, ovis.

overview of assemblage properties, in order to be useful as a broadly applicable research tool additional, assemblage-specific properties need to be examined. Counts of articular ends and shaft fragments should be compiled in ways that allow application of independent techniques for investigating articular end destruction.

A plot of articular end frequencies by the number of shafts and shaft fragments for bison and bighorn sheep from Bugas-Holding (Figure 9) indicates two types of fragmentation. For the bison, the number of articular ends and shaft fragments are positively correlated. On the other hand, bighorn sheep fragments are negatively correlated. The bighorn sheep tibiae, femora and humeri form a group with an overabundance of shaft fragments, whereas the radii and metapodials have more articular ends than shaft fragments. This indicates greater destruction of articular ends of some sheep limb bones than on corresponding bison limbs. However, as we have noted previously, several techniques are often required in order to limit the uncertainty of such interpretations.

Recently, Bunn & Kroll (1986) have argued that long bone shaft fragment frequencies at the FLK *Zinjanthropus* floor indicate that once-present articular ends have been destroyed or removed from the site. Their estimate of the number of elements represented on shaft fragments is based on attention

to areas of overlap of homologous parts, to conjoining, to differences in size and morphology, and to other attributes that could categorically and unambiguously rule out that two different specimens originally formed parts of the same complete bone (Bunn & Kroll, 1986: 435).

While determination of the number of elements represented by shaft fragments within an assemblage is indeed valuable information, Bunn & Kroll's (1986) description would initially seem to imply a subjective comparison of each shaft fragment. Subjective comparison of all shaft fragments is susceptible to development of inflated shaft counts, since

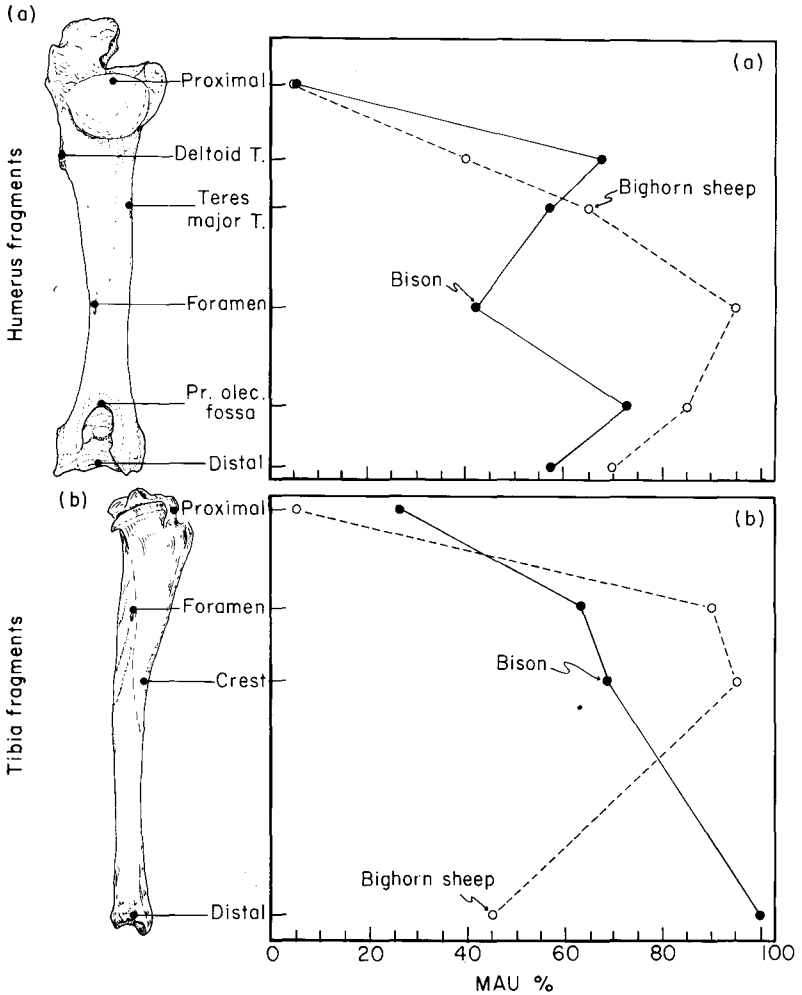


Figure 10. Relative frequencies (standardized MAU values) of identifiable distinct portions of (a) humeri and (b) tibiae from the Bugas-Holding site.

it is possible for even slight judgmental errors to lead to non-adjacent fragments of a single element being counted as individual bones. However, Bunn's earlier (1982: 34) description of the shaft fragments indicates that a primary consideration in the evaluation of the possibility that pieces may have come from a single bone was the presence of identifiable, unique landmarks such as foramen, which are the "homologous parts" referred to by Bunn & Kroll (1986: 34; see also Watson, 1979: 129).

As an extension of this technique, documentation of the Bugas-Holding materials (Table 4) uses explicit counts of specific, readily identifiable anatomical features of long bone shafts such as nutrient foramen or muscle attachments [like the deltoid tuberosity portion in Figure 5(f)] as the basis for determining shaft MNE values. For example, portions recorded for humeri include: the proximal articular end, the deltoid tuberosity, the teres major tubercle, the posterolateral nutrient foramen on the distal shaft, the proximal-most portion of the olecranon fossa and the distal articular end. A complete

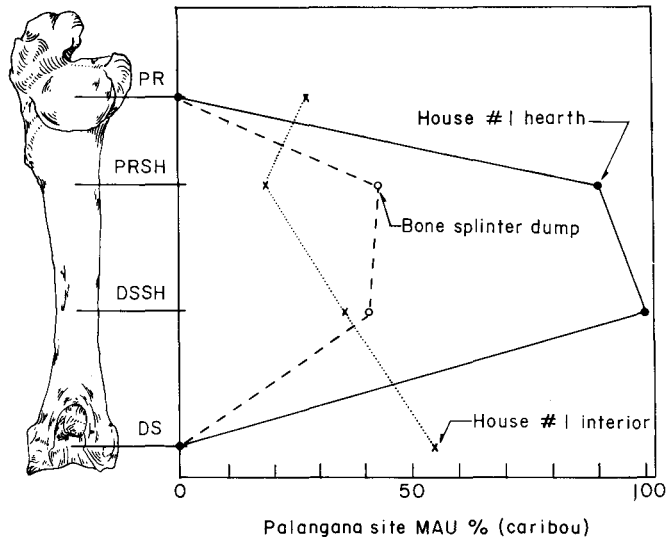


Figure 11. Spatial variability in caribou humerus shaft fragment frequencies at the Palangana site (from Todd *et al.*, 1985). PRSH frequency is based on deltoid tuberosity counts; DSSH frequency based on nutrient foramen count.

humerus has one of each of these portions. These are all portions that can usually be identified to side and body size class even within highly fragmented assemblages. Since there is only one of these landmarks per element, there is no possibility of a single bone being counted several times for a given portion. A single fragment may, however, have several of the landmarks. For example, it is fairly common for proximal articular surfaces of radii to have attached radial tuberosities. In such cases, each portion is included in its appropriate MNE category (e.g. one proximal end and one radial tuberosity). While the use of shaft landmarks can produce more refined counts of fragmented assemblages, the problem of how to incorporate fragments without unique landmarks or with partial landmarks into comparative investigations should be addressed in subsequent investigations.

Using standardized MAU values (Binford, 1984) of identifiable shaft portions listed in Table 4, the relationships among articular ends and shafts of the Bugas-Holding humeri [Figure 10(a)] and tibiae [Figure 10(b)] are compared. For both bison and bighorn sheep, there are greater numbers of shafts than distal articular ends. In the case of the bison, three young animals with incomplete epiphyseal union of the distal ends are missing the articular portions and account for the greater number of proximal olecranon portions in the assemblage. The posterolateral nutrient foramen count for the bighorn sheep indicates that at least five more elements are represented by shafts than by distal articular ends (Table 4: MNE). This tends to confirm the suggestion based on the plot of shaft fragments against articular ends (Figure 9) that bighorn long bone shafts outnumber articular ends in the excavated portions of the Bugas-Holding site. The relative frequencies of tibiae portions [Figure 10(b)] clearly illustrate this difference with distal articular ends being the most common bison tibia portion represented, whereas the shaft fragments (tibial crest portions) of the bighorn sheep outnumber the distal ends by more than 2:1.

In addition to the examination of assemblage level patterning, the documentation of shaft portion representation and fragmentation can also be used in the investigation of spatial patterning within archaeological sites. As an illustration of this point, several

discrete groups of caribou bones from the Palangana site (see Binford, 1983: 176–184) have been tabulated in the same way as the Bugas-Holding bones (Todd *et al.*, 1985). Portions of humeri in two bone clusters—an outside bone splinter dump (Binford, 1983; figure 122) and a pile of bone fragments adjacent to an interior hearth (see Binford, 1983: figure 117)—are compared with the other bone from the house interior in Figure 11. In both the outside splinter dump and the hearth-side pile, shaft fragments predominate, whereas the other bones within the house interior (excluding those in the hearth-side pile) are more commonly represented by articular ends. Such spatial differences in fracture patterns can be useful components in recognition and analysis of distributional patterns within archaeological sites.

Conclusions

Assemblage level comparisons, based on broadly applicable techniques such as those described here, can aid in the development of more reliable interpretations of the role of animal resources in past human adaptations. While the limited number of cases in the present sample precludes any general behavioural interpretations, several general points about the analysis of fragmented long bones can be made.

First, comparative investigation of assemblage level fracture patterning can be accomplished using simple techniques that do not require major changes in current faunal assemblage recording techniques. Second, as with most analyses, no single technique provides all the answers. Investigation of faunal assemblage patterning requires a variety of procedures so that a battery of techniques, each highlighting different components of element fragmentation, can be applied as directed by the development of research programs. Finally, in many archaeological faunal assemblages much of the breakage recorded during excavation or analysis is the result of a variety of processes in addition to human processing. Documentation and comparison of fracture patterns is an initial step in the search for ways to distinguish which of a variety of processes may have acted on an assemblage. Continued development and application of comparative techniques such as those explored here can serve as the basis for more reliable statements about patterning within archaeological faunal assemblages.

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