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Detecting the Postburial Fragmentation of Carpals, Tarsals, and Phalanges

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Introduction

During the past 30 years paleontologists and zooarchaeologists have displayed a serious interest in taphonomy, a term originally coined and defined by Russian paleontologist I.A. Efremov (1940) as the study of the transition of organic remains from the biosphere into the lithosphere. Weigelt (1927; English translation, 1989) had previously proposed the term *biostratinomy* and defined it as the effects on organic remains that take place between the time of an organism's death and the burial of its remains. Muller (1963) later proposed the term *diagenesis* to denote the effects on organic remains that take place between the time of their burial and their recovery by a paleontologist or zooarchaeologist. Taphonomy, therefore, concerns both the biostratinomic and diagenetic phases of what Efremov referred to as the science of the laws of embedding or burial.

The burst of interest in taphonomy during the past 30 years has resulted in a marked increase in the number of published articles on the formation of the geological record of past life, particularly zoological life (Donovan, 1991; Lyman, 1994c). In zooarchaeology, the literature has focused most closely on deciphering taphonomic traces that signify aspects of biostratinomy for two reasons. First, this phase of taphonomic history is the one during which hominid taphonomic agents have their most direct input to the accumulation, modification, and deposition of faunal remains and, thus, is the one of most concern to zooarchaeologists interested in past human behavior (e.g., Hudson, 1993). Second, the processes comprising the biostratinomic phase are much more readily studied in an actualistic context than the processes operating during the diagenetic phase.*

Literature concerning the digenetic phase of taphonomy has tended to be written largely by paleontologists who focus on fossilization processes, or those that maintain or alter the chemical composition of organic remains (e.g., Donovan, 1991). The few contributions by zooarchaeologist examining diagenetic processes center on recognizing what is often mislabeled as "postdepositional" fragmentation (e.g., Klein, 1989; Klein and Cruz-Uribe, 1984:69–75; Marean, 1991; Villa and Mahieu, 1991). We say mislabeled because although deposition can be coincident with burial, actualistic research indicates that deposition can also, and often does, precede burial by various, sometimes taphonomically significant, lengths of time (e.g., Behrensmeyer, 1978). Marean (1991:677) defined "postdepositional processes ... as including chemical and mechanical action on bones and teeth after the bones and teeth have entered the sediment and are no longer sources of food for mammals." Although we agree with this definition, we prefer the term *postburial* because it avoids potential confusion that may result from use of the term *postdepositional*, particularly when it is not defined.**

Researchers have attempted to discern the degree of fragmentation of faunal remains that is attributable to the weight of overburden and sedimentary compaction. It is suggested by some that the influence of these factors is greater on bones that have undergone chemical leaching and, therefore, are structurally weakened. Study of the degree of postburial fragmentation is important for several reasons. Most fundamentally, fragmentation influences identifiability and, hence, measures of abundance. An assemblage of broken bones and teeth

* Actualistic research comprises observation, in this case, of taphonomic processes, documentation of the effects of these processes, and use of the latter to infer that similar processes produced similar effects in the past.

** In the present context, burial need not be a result of intentional human behavior. It can simply be the result of natural geological processes involving deposition of sediment.

will produce higher NISP (number of identified specimens) counts than a taxonomically and skeletally identical assemblage of unbroken bones and teeth. Further, as individual skeletal elements become progressively more broken, the NISP value progressively decreases (Lyman, 1994b; Marshall and Pilgrim, 1993). This decrease occurs because smaller fragments are less likely to retain anatomically and taxonomically diagnostic landmarks.

In this chapter we examine and expand one proposed method for recognition of diagenetic or postburial fragmentation so that it might be distinguished from biostratinomic fragmentation. Much of what we discuss owes its presence in the taphonomist's analytical tool kit to the seminal work of others, and our contribution to the study of digenetic processes builds upon this research. We view our efforts here as another small step toward developing taphonomic methods that will allow paleontologists and zooarchaeologists (and perhaps forensic scientists) to decipher taphonomic histories of assemblages of bones and teeth, particularly the little-explored diagenetic phase of those histories.

Background

Several years ago zooarchaeologist Curtis Marean (1991:692) hypothesized that "a bone's resistance to postdepositional destruction is determined by its density, size and shape mediated by the postdepositional process involved (chemical or mechanical)." Marean did not evaluate this hypothesis, but instead described a method that he believed would allow analytical recognition of postburial fragmentation of bones. He discussed three prerequisites to his method: two concerned the skeletal elements used in the analysis and the other concerned quantification of bone specimens.* Skeletal remains to be used should, Marean reasoned, be those (a) that are seldom if ever broken by hominids or carnivores and (b) whose relative frequencies are not influenced by bone accumulation processes. Last, the unit of quantification should not be subject to inter-observer variation. The first and second requirements were met by using carpals and tarsals,** skeletal elements that Marean (1991) argued were seldom broken by hominids and carnivores and that all underwent similar transportation histories in actualistic contexts. He, therefore, reasoned that the relative frequencies of these skeletal elements would not be influenced by these processes, but perhaps would be by postburial processes.

Marean met his third requirement by using a "completeness index" to characterize the degree of fragmentation. The completeness index "is derived by estimating for each specimen the fraction of the original compact bone that is present, summing the values, and dividing that by the total number of specimens ascribed to that bone and taxon" (Marean, 1991:685). For example, if three specimens of the astragalus are present, and one is complete (1.0), one comprises half of an astragalus (0.5), and one comprises a quarter of an astragalus (0.25), then one solves the equation $[(1.0 + 0.5 + 0.25)/3] \times 100 = 58.3$ to derive a percent completeness index (CI%) for the astragalus. The CI% value is properly read as the average completeness of the specimens for the skeletal element under consideration, such that in the preceding equation the value denotes that these three astragali are, on average, 58.3% complete skeletal elements.

* A *skeletal element* is defined as "a single complete bone or tooth, a discrete, complete anatomical organ" (Lyman, 1994b:290). A *specimen* is "a discrete bone or tooth, or fragment thereof" (Lyman, 1994b:290).

** For purposes of brevity, we include the distal fibula, also known as the lateral malleolus, in the (artiodactyl) tarsal category.

Marean (1991) noted that under experimental conditions hyenas often ingested articulated carpals and articulated tarsals: carpals seldom, if ever, displayed gnawing damage whereas among the tarsals only the calcaneum displayed such damage, and it did so only about half of the time. Both carpals and tarsals displayed corrosion subsequent to their ingestion and passage through the digestive tract. Marean reasoned that specimens displaying digestive corrosion should be omitted from calculation of the CI%. Similarly, he argued that specimens that had been burned should also be omitted because they are more brittle than unburned specimens (Stiner et al., 1995), and specimens that were heavily weathered (Behrensmeyer, 1978) should be omitted because of the possibility that cracks produced by subaerial weathering would result in greater fragmentation than unweathered specimens subsequent to burial. Finally, he indicated that carpals and tarsals displaying percussion damage should be omitted from specimens used to derive the CI% value because that value is meant to measure postburial fragmentation. The unnoted assumption underpinning the last is that percussion damage will result *only* from the impact of human-wielded hammerstones, an assumption we find untenable if the bones were recovered from a cave whose roof produces rock spalls that fall to the cave floor.

When comparing the assemblages of artiodactyl carpals and tarsals from two African cave sites, Marean (1991:687) concluded that one assemblage had undergone much more "postdepositional destruction" than the other largely because the CI% was consistently lower across different carpals and tarsals in one collection than in the other. He also noted that (a) larger skeletal elements such as the astragalus and naviculo-cubiod displayed the greatest differences in CI% between the two assemblages and thus would likely provide the most reliable indication of postburial fragmentation, and (b) taxonomic differences in body size indicated that (larger) skeletal elements of larger taxa had lower CI% values than homologous elements in smaller-bodied taxa. Both of these observations suggest that larger bones tend to be more prone to fragmentation, before or after burial, than smaller bones.

Expanding the Method

Marean (1991) suggested that collections with low CI% values indicate greater postburial fragmentation than those with high CI% values. Such an interpretation rests on a limited number of experiments and theoretical reasoning that suggest carpals and tarsals meet the criteria Marean specified for detecting postburial destruction. Actualistic research cited by Marean (1991), however, indicates that hominids do sometimes fracture carpals and the smaller tarsals. How, then, is fragmentation resulting from biostratinomic processes to be disentangled from fragmentation resulting from diagenetic processes? The theoretical reasons for analysis of carpals and tarsals relate to their mechanical properties as sedimentary particles and their value as food sources for predators relative to other skeletal elements. The former relates to Marean's hypothesis that postburial fragmentation is mediated by density, size, and shape. The food value, as we indicate below, is also influenced by their size and shape. Consideration of each of these factors suggests ways to evaluate and expand Marean's method for recognizing postburial fragmentation.

Mechanical and Nutritional Properties of Skeletal Elements

Carpals and tarsals are, by and large, compact skeletal elements. They tend to be structurally dense (Table 19.1), and they also tend to be spherical in shape (Figure 19.1). The notable

Table 19.1 Structural Density, Volume (ml), Marrow Utility, and Grease Utility Values of Artiodactyl Carpals, Tarsals, and Phalanges

Skeletal Element	Structural Density[a]	Volume	Marrow Utility Index[b]	Grease Utility Index[b]
Carpals			(1.0)	(36.47)[c]
Cuneiform (ulnar carpal)	0.72	2	1.0[d]	5.03[e]
Lunar (intermediate carpal)	0.83	3	1.0[d]	7.55[e]
Pisiform (accessory carpal)	—[f]	1	1.0[d]	2.51[e]
Scaphoid (radial carpal)	0.98	3.5	1.0[d]	8.80[e]
Trapezoid magnum (carpal 2 +3)	0.74	3	1.0[d]	7.55[e]
Unciform (fourth carpal)	0.78	2	1.0[d]	5.03[e]
Tarsals			(1.0)[c]	(29.87)[c]
Calcaneum	0.64	18	21.19	46.96
Astragalus	0.61	12	1.0	32.47
Naviculo-cuboid	0.62	8.3	1.0[d]	21.56[e]
Tarsal 2 + 3 (external cuneiform)	—[f]	2	1.0[d]	5.19[e]
Distal fibula (lateral malleolus)	0.52	1.2	1.0[d]	3.12[e]
Phalanges				
First phalanx	0.57	6	30.00	33.27
Second phalanx	0.35	4.3	22.15	24.77
Third phalanx	0.25	3.7	1.0	13.59

[a] Values are for deer (*Odocoileus* sp.) and are the greatest recorded of several taken for calcaneum, naviculo-cuboid, astragalus, first phalanx, and second phalanx. (From Lyman, R.L., *Vertebrate Taphonomy*, Cambridge University Press, Cambridge, U.K., 1994c, pp. 246–247.)

[b] From Binford, L.R., *Nunamuit Ethnoarchaeology*, Academic Press, New York, 1978, pp. 27, 33.

[c] Values in parentheses for all carpals as a single unit and, we assume, for the naviculo-cuboid, tarsal 2 + 3, and distal fibula as a single unit. (From Binford, L.R., *Nunamuit Ethnoarchaeology*, Academic Press, New York, 1978, pp. 27, 33.)

[d] Values assigned by Darwent and Lyman (see text for discussion).

[e] Values derived and assigned by Darwent and Lyman (see text for discussion).

[f] No data available.

exception to the latter is the calcaneum, a skeletal element that has a more rod-like shape. Artiodactyl carpals and tarsals all tend to have rather low nutritional values; they contain minimal amounts of grease and virtually no marrow, as indicated by Binford's (1978) grease and marrow utility indices (Table 19.1). The theoretically significant points here are two. First, the relatively high structural density (g/cc) of these elements means that they require a great deal of force to break (Currey, 1984). In combination with the fact that carpals and tarsals have minimal interstitial space containing grease and marrow, this suggests that these elements would seldom be broken by hominids in order to extract potential sources of nutrition because the cost — particularly using primitive technologies — may well outweigh the return. For example, Marean's (1991: 691) experiments prompted him to suggest "an extraordinary effort is required to break fresh compact bones by hammerstone percussion." Carnivores may extract nutrients by ingesting carpals and tarsals whole, as documented by Marean's (1991) experimental feeding of hyenas.

The second important point with respect to the mechanical properties of bones is that relatively solid spheres, particularly small ones, can withstand significant compression and other forces without deformation or fracture. Hollow spheres (such as crania), solid or hollow rods (such as long bones), or solid or hollow plate-like structures (such as innominates and scapulae) cannot withstand forces of similar magnitude (Currey, 1984:147–150),

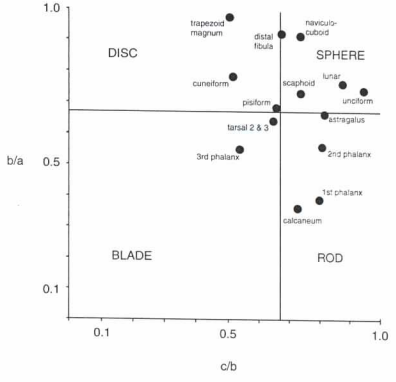

Figure 19.1 Classification of shape of carpals, tarsals, and phalanges.

particularly if their groundward surface is not uniformly in contact with the sediments on which they lie. Tarsals, with the exception of the calcaneum, and carpals are small and relatively spherical and thus their groundward surface is typically in uniform contact with the sediments on which they lie. Thus, they are unlikely to be regularly fractured by mere sediment overburden weight, which is not to say that they will *never* be broken by this taphonomic factor. For example, catastrophic burial, such as a roof-fall event within a cave, may not only bury bones, but fracture them as well (e.g., Thomas and Mayer, 1983). Chemical leaching no doubt weakens all bones, but we have no data to evaluate this diagenetic process and do not consider it further here.

If small spherical bones such as carpals and tarsals (except the calcaneum) are unlikely to be fractured except by diagenetic processes, then first and second phalanges should be more frequently broken than carpals and tarsals of the same taxon (Figure 19.1). This is because these phalanges contain more marrow and grease than carpals and tarsals (Table 19.1), and thus are more likely to be broken by predators (hominids or carnivores) during the biostratinomic phase. The second phalanx is also more likely to be broken than a carpal or tarsal because it is a hollow bone of rod-like shape, resulting in a greater probability of diagenetic fracture. First phalanges should be more broken than second phalanges because they are hollow rods and are longer than second phalanges, resulting in a greater probability of diagenetic fracture. For the same reason, the calcaneum, a relatively rod-like bone (Figure 19.1) with some marrow and grease (Table 19.1), should be relatively more broken than other tarsals and carpals as a result of both biostratinomic and diagenetic processes.

There are two assumptions underlying the statements in the preceding paragraph. First, we assume that during the biostratinomic phase, hominids and carnivores that are fracturing bones for purposes of grease/marrow extraction will break these bones in direct proportion to (a) their grease/marrow content and (b) ease of fracture (shape, size, and density related). Second, we assume that the probability that diagenetic processes will result in fragmentation decreases as skeletal element shape shifts from rod-like to sphere-like, and as skeletal elements increase in density (decrease in food utility) and decrease in size. Note what is said in the two immediately preceding sentences. Predators acting during the biostratinomic phase will break skeletal elements relative to the ease of element fracturing, and diagenetic processes will break skeletal elements relative to their shape, density, and size, or their ease of fracture. In other words, we suspect Marean's hypothesis that the fragmentation of skeletal elements will be mediated by the elements' shape, density, and size is correct, but that it is correct regardless of the fracture agent. This belief leads us to suggest an expansion to Marean's (1991) method.

Marean focused exclusively on bones he thought would most likely not be broken during the biostratinomic phase; in his view, these are the carpals and tarsals. He noted that the calcaneum has a "small marrow cavity that may entice predator fragmentation" and thus he thought it "best to exclude calcanea from any analysis of postdepositional [postburial] destruction" (Marean, 1991:681). The same argument could be made for the first and second phalanges. We think it unlikely, however, that postburial fragmentation and destruction will be limited to only those skeletal elements not broken during the biostratinomic phase. In particular, we suspect that there will be a continuum from a low to a high degree of fragmentation, and that this continuum will correlate directly with several variables: bone shape as it alters from spheroid to rod-like or blade-like; bone size as it alters from small to large; and marrow and grease utility as these alter from minimum to maximum values. We also suspect that the degree of fragmentation will correlate inversely (coefficients will be negative) with structural density because as density decreases, skeletal elements will be less strong structurally. We expand Marean's method and include phalanges and calcanea in our analyses below to evaluate our suspicions of a continuum of fragmentation. If statistically significant correlations are found between the degree of fragmentation and the food utility, shape, size, and density of skeletal elements, then it can be argued that the mere presence of fragmented carpals and tarsals is insufficient to indicate postburial fragmentation.

Quantification

Marean's (1991) CI% value was proposed as an improvement to other means of measuring the degree of fragmentation, particularly that proposed by Klein and Cruz-Uribe (1984), who suggested that a NISP:MNI or NISP:MNE* ratio would provide a measure of fragmentation. In proposing the CI% value, Marean (1991:680) was correctly concerned that inter-observer variation in both (a) how MNI and MNE values were calculated, and (b) which identified specimens were included in the calculations, would influence results. The first concern hinges on the fact that MNI and MNE values are derived rather than observational

* MNI values are derived from sets of all identified specimens and represent the minimum number of individual animals necessary to account for the specimens. MNE values are derived from sets of specimens of particular skeletal elements and represent the minimum number of skeletal elements necessary to account for the specimens.

and thus they can be determined in various ways (e.g., Grayson, 1984; Lyman, 1994a). We believe, however, that if the observer is consistent within an analysis, then the MNI and MNE values will be consistently derived. We also believe that variation in the inclusion of specimens can influence not only NISP:MNI and NISP:MNE ratios, but the CI% value because the latter also depends on which specimens are included in the tally. Therefore, although we understand Marean's concerns, we find them incompletely resolved by the use of the CI%.

Consistent application of criteria for inclusion of specimens in NISP tallies and for derivation of MNE and MNI values should circumvent the problems Marean identifies. Of course, there will always be variation between analysts in terms of what, for example, Lyman believes is identifiable and what Darwent does. In other words, inter-observer bias will always be a problem, regardless of which measure of fragmentation is used.

The NISP:MNE ratio is elsewhere termed the *intensity of fragmentation* (Lyman, 1994b:294). Lyman (1994b:294) suggested one could measure the *extent of fragmentation* as the "proportion of specimens [of a particular skeletal element] that are complete" or "%Whole," and that in conjunction with the intensity of fragmentation, these two measures would provide two indices of the degree of fragmentation. The extent of fragmentation is easily observed within a collection as long as what is tallied as a complete or whole specimen is consistent from specimen to specimen. Unlike the CI%, the NISP:MNE ratio depends on whether specimens overlap anatomically or not; that is, for the intensity of fragmentation, the distal half of two humeri, both from the same side, would be tallied as a ratio of 2:2 (reduced to 1:1), whereas the CI% would be 50%. The former ratio would be 2:1 if one proximal half and one distal half that did not overlap anatomically were represented, whereas the CI% would still be 50% in this case. Our point here is that the different indices — CI%, NISP:MNE, %Whole — measure different properties of a collection (Lyman, 1994a). Is one more correct than the other?

The only way that the preceding question can be answered is to agree on a variable that we wish to measure. The variable of interest in studies of postburial fragmentation is the *degree of fragmentation*, or what we define as a measure of how broken skeletal elements are. All three indices — CI%, NISP:MNE, %Whole — measure this variable. As we noted earlier, the CI% can be read as "the average completeness of specimens of element X." The NISP:MNE ratio, too, is a statement concerning the completeness of specimens because it expresses the average number of specimens per skeletal element.* The NISP:MNE ratio contains the same information as the CI%, but it also contains the additional information of specimen overlap as expressed by the MNE. The %Whole index indicates the proportion of all specimens that are anatomically complete or that comprise an entire skeletal element, thus its information content overlaps with, but is less than, the other two because it only indirectly accounts for specimens comprising incomplete skeletal elements. In one sense, then, the amount of information regarding fragmentation increases from %Whole (with the least information), to CI%, to NISP:MNE. Because of information overlap, the latter

* When Lyman (1994b:294) discussed the NISP:MNE index, he suggested that complete skeletal elements — whole bones — should not be included in the calculation. This suggestion was made there because the goal was to answer the two-part question, "How anatomically complete are the incomplete specimens, and how much anatomical overlap do incomplete specimens display?" The CI% merely asks, "How anatomically complete are *all* the specimens, on average?" Including anatomically complete specimens in the NISP:MNE ratio addressed the two-part question, "How anatomically complete are *all* specimens, on average, and how much anatomical overlap do the total specimens display?"

two should be inversely correlated (see also Marean, 1991:689–690); and, the %Whole and CI% should also be correlated when the former is large across multiple skeletal elements because when this occurs, the CI% will also be large.

The preceding suggests that Marean's (1991) method may be expanded to include three indices of fragmentation. Each index contains similar information, but each also contains unique information. Correlations between the various fragmentation indices, or lack thereof, and the structural density, size, or shape of the skeletal elements may reveal aspects of fragmentation not otherwise discernable were only one of them used during analysis. Incorporation of the size, structural density, and shape of the bones into the analysis addresses Marean's hypothesized relationship between these variables and the different aspects of the degree of fragmentation captured by the CI%, NISP:MNE, and %Whole indices.

Methods, Materials, and Caveats

We chose a sample of bones recovered from archaeological deposits in Moses Coulee Cave (45DO331) in eastern Washington State, to evaluate and expand on Marean's (1991) method. We chose this particular sample because (a) carpals, tarsals, and phalanges are abundant; (b) the majority of the specimens represent a single taxon; and (c) its postburial taphonomic history comprised a unique stage that potentially fragmented some of the specimens. Temporally diagnostic artifacts associated with the faunal remains span the last 10,000 years, and the bones we discuss here date to that entire time span. Finer temporal resolution is not possible because the site was not professionally excavated. Rather, the sediments within the cave and at the cave mouth were removed and redeposited several meters away from and in front of the cave in 1932 by a Fresno (Lyman, 1995).*

The relocated sediments, the "spoils pile," were screened and artifacts and faunal remains collected in 1988 and 1989 by avocational archaeologists. Lyman (1995) studied the faunal remains in 1993 and reported on the taxonomic composition of the collection. The majority of the bones from Moses Coulee Cave were readily identified as bighorn sheep (*Ovis canadensis*, NISP = 2190); a few represented deer (*Odocoileus* sp., NISP = 88), pronghorn antelope (*Antilocapra americana*, NISP = 19), wapiti (*Cervus elaphus*) NISP = 4, and bison (*Bison bison*) or domestic cow (*Bos taurus*, NISP bison + cow = 198) (bones modified into artifacts and isolated teeth were omitted).

We reexamined the carpals, tarsals, and phalanges of deer-sized artiodactyls for purposes of analyses discussed here. Specimens of bighorn sheep, deer, pronghorn antelope, and those deer-sized bones that could not be identified to species are included. The fact that multiple taxa are included should have minimal influence on analytical results. This is true for two reasons. First, the three taxa are similar in size and basic body plan, and their bones are similar in size, shape, and density, so taxonomic differences are unlikely to have contributed to variation in the taphonomic histories of individual specimens. Second, it is likely that the majority of the carpals, tarsals, and phalanges discussed here represent bighorn sheep. This is because the specimens of these elements that were sufficiently

* A Fresno is so-called because the Agricultural Works of Fresno, California, were a major manufacturer of them. A Fresno, also known as a buck scraper, is an earth digging and transporting device consisting of a crescent-shaped, bottomless bucket or scoop that is dragged along the ground. It has two runners upon which the scoop is lifted when it is filled.

Table 19.2 Frequencies (NISP) of Carpals, Tarsals, and Phalanges of Bighorn Sheep, Deer, Pronghorn Antelope, and Deer-Sized Specimens from Moses Coulee Cave

Skeletal Element	Bighorn Sheep	Deer	Pronghorn Antelope	Deer-Sized[a]
Cuneiform	58	1	—	4
Lunar	55	8	—	22
Pisiform	—	—	—	42
Scaphoid	72	6	—	15
Trapezoid magnum	94	2	—	22
Unciform	—	—	—	79
Calcaneum	63	—	—	184
Astragalus	—	—	—	325
Naviculo-cuboid	51	3	1	57
Tarsal 2 + 3	—	—	—	97
Distal fibula	—	—	—	74
First phalanx	203	1	1	265
Second phalanx	155	7	1	—
Third phalanx	106	7	—	—

[a] Counts differ from Lyman (1995) because some specimens could not be relocated, and some new specimens were identified.

anatomically complete to allow identification to species are dominated by bighorn sheep remains (Table 19.2). Thus, even if specimens of multiple taxa are included in NISP tallies, the few non-bighorn specimens will have minimal influence on these tallies and on analytical results.

We followed Marean's (1991) procedure and recorded various data for each specimen. The skeletal element represented, whether it was burned, excessively weathered, corroded as a result of digestion, displayed carnivore or rodent gnawing damage, displayed butchering marks such as chopping or percussion scars, were recorded.* Modern fractures were noted when the fracture surface was a lighter color than an unfractured surface of a specimen. We also noted if the proximal epiphysis of first and second phalanges were fused to the diaphysis, and if the tuberosity of the calcaneum was fused to the shaft. If a specimen was incomplete, we evaluated its completeness by superimposing it on a 2-mm grid and estimating the amount remaining relative to a complete specimen. To insure against inter-observer variation, Darwent recorded all data discussed here.**

Faunal remains recovered from Moses Coulee Cave included specimens representing five genera and at least six species of carnivore. These include the gray wolf (*Canis lupus*, NISP =1); dog (*C. familiaris*) or coyote (*C. latrans*) (NISP = 38); red fox (*Vulpes vulpes*,

* A number of carpals and tarsals have cut marks, but we do not consider them here. Similarly, few specimens display modern damage such as may have resulted from the 1932 mechanical movement by the Fresno of the sediment and bones; if present, such damage is superficial.

** To test for inter-observer bias in estimating specimen completeness, Darwent selected a sample of 10 first phalanx specimens and 10 naviculo-cuboid specimens. Lyman then estimated the completeness of each specimen and calculated the CI% for both samples. For the phalanges, Lyman's CI% was 31.5% and Darwent's was 34%; for the naviculo-cuboid, Lyman's CI% was 42.5% and Darwent's was 44.0%. This small test suggests inter-observer variation may influence CI% values.

NISP = 7); long-tailed weasel (*Mustela frenata*, NISP = 1); badger (*Taxida taxus*, NISP = 4); and bobcat (*Lynx rufus*, NISP = 1). Of these, the canids and badger are the most likely to have created the gnawing and digestive corrosion damage evident on some of the carpals, tarsals, and phalanges (Lyman, 1995)

In his experiments, Marean (1991) found that when metapodials were laid on an anvil and broken with a hammerstone, surfaces of carpals and tarsals articulated with the metapodials lacked percussion scars. He reasoned that the latter occurred because the carpals and tarsals "are encased in a thick and resistant ligament and tendon mass that cushions them from hammerstone blows" (Marean 1991:681). He also found that when carpals and tarsals are intentionally broken with a hammerstone, "the force needed to break a compact bone is so great that the hammerstone/anvil impact marks on the compact bone are extremely prominent and easily recognized" (Marean, 1991:681). Marean referenced Blumenschine and Selvaggio (1988) as illustrating the kinds of impact marks he found, and we consulted this paper, as well as a related one (Blumenschine and Selvaggio, 1991).

To insure that we knew the kinds of attributes to look for when searching for percussion damage and to be able to recognize them, we experimentally broke carpals, tarsals, and phalanges of domestic pig (*Sus scrofa*) with a hammerstone. All specimens had been defleshed by boiling, and we chose specimens that were still greasy to replicate possible prehistoric conditions. We laid individual skeletal elements on a smooth hard surface (anvil), and struck them with a quartzite cobble. After fragmentation, we collected all fragments and inspected them for evidence of impact damage.

In light of Marean's statements, our observations are rather disconcerting. Percussion damage to some specimens was minimal; refitting fragments sometimes made it easier to detect the damage such as when an articular surface of adjacent fragments did not match up smoothly across two refit specimens. Further, some phalanges were broken, yet none of the resulting specimens displayed what we could unambiguously term percussion damage. The shaft or diaphysis was simply broken. No crushing of what a lithic technologist calls the platform or point of impact was observable. The same applied to some carpals and tarsals; a few of these simply broke or split into pieces. Finally, some specimens of all elements did not display percussion damage of any kind; for example, the 10 astragali we broke produced a total of 70 fragments (individual astragali produced 3 to 16 pieces). Of those 70 fragments, only 12 (17%) clearly displayed percussion damage; 2 astragali, 1 that broke into 3 pieces and another that broke into 7 pieces, produced no specimens with impact damage.

Our observations have, we believe, extremely significant implications. They suggest that omitting specimens with percussion damage from derivations of fragmentation indices will not eliminate all specimens that were produced by hammerstone-generated fracturing. Because we as yet do not know how to account for this fact, we largely ignore it in our analysis. Further, we are unsure of the reason behind our results apparently not mimicking Marean's. Perhaps it is because we did not precisely replicate his experimental protocol. We do not know, for example, if the carpals and tarsals he broke were defleshed, nor do we know the precise kinds of percussion damage he sought and found to be "extremely prominent and easily recognized." And, Marean does not say that *every* specimen of carpal and tarsal generated by his breaking bones with a hammerstone retained percussion damage. Clearly, there is a need for more rigorous experimental fracturing of carpals, tarsals, and phalanges and more rigorous documentation of such, but we caution that all such

experiments may be of more or less limited utility because of the particular historical contingencies of every instance of fragmentation.* With that caveat in mind, we turn to our analysis of the Moses Coulee Cave specimens.

Results

The taxonomic and skeletal composition of the assemblage of carpals, tarsals, and phalanges we examined is summarized in Table 19.2. In this section, we ignore taxonomic distinctions and summarize other data we recorded for this collection and describe our analyses of these data. Because many of our analyses involve calculating the degree of correlation between certain variable pairs, we describe these variables and note their significance before turning to detailed analyses.

Skeletal Element Frequencies

There are a number of reasons why the frequencies of the different skeletal elements we consider here may vary. Given our analytical focus on fragmentation, two of the reasons are important in the present context. First, smaller specimens (especially fragments) may have been less often recovered than large specimens. To explore recovery bias, we correlated the frequency of complete specimens of each skeletal element with the average maximum dimension and also with the average minimum dimension of each. Our reasoning in doing so is simple. If recovery methods resulted in a biased collection, the smallest specimens would be the ones most likely to be overlooked and not recovered (e.g., Schaeffer, 1992; Watson, 1972), irrespective of whether a specimen represented a complete skeletal element. Recovery bias would, therefore, be reflected by a positive correlation between specimen size and frequency. Rather than measure each individual specimen, we used the maximum and minimum dimensions of complete skeletal elements as the measure of size. Our assumption was that handpicking specimens from sediments would depend on their maximum size, and recovering specimens from screens would depend on their minimum size.

Relevant data are given in Table 19.3. There is no significant correlation between the minimum dimension and the number of whole skeletal elements (Spearman's rho = –.244, $p = .4$) nor between maximum dimension and the number of whole skeletal elements (rho = –.407, $p = .15$). These statistics, in conjunction with the facts that some specimens included in the NISP counts are less than 1 cm^3 in size, and that .25-in. mesh screens were used to recover the remains (Lyman, 1995), suggest that recovery methods did not result in failure to collect small fragments of the skeletal elements under study here.

The second reason specimen counts may be biased is that skeletal elements of lower structural density may have been more frequently destroyed by biostratinomic or diagenetic processes. One way to detect such destruction is to determine if the structural density of each skeletal element is inversely correlated with the NISP of each skeletal element. Our reasoning here is that skeletal elements of low structural density should be more fragmented (perhaps to the point of destruction or analytical invisibility) and thus have higher NISP

* Although a machine could be built to precisely replicate the amount of force applied and the point of force application in test after test, microstructural variation in, say, each astragalus broken in conjunction with variation in amounts of adhering soft tissue and grease content would undoubtedly result in variation in fracturing and percussion damage.

Table 19.3 Number of Whole Specimens, Average Minimum Dimension, and Average Maximum Dimension for Each Skeletal Element

Skeletal Element	Number Whole[a]	Minimum Dimension[b]	Middle Dimension[b]	Maximum Dimension[b]
Cuneiform	44	10.2	19.5	25.0
Lunar	56	15.5	17.7	23.3
Pisiform	22	8.4	12.8	18.8
Scaphoid	59	12.7	17.2	23.6
Trapezoid magnum	75	10.5	20.8	21.4
Unciform	53	13.3	14.6	19.6
Calcaneum	12	22.3	30.4	84.5
Astragalus	60	21.4	26.0	39.4
Naviculo-cuboid	27	20.8	28.1	30.8
Tarsal 2+3	67	8.6	13.2	20.7
Distal fibula	48	12.0	17.5	19.0
First phalanx	10	16.5	20.5	52.7
Second phalanx	38	14.8	18.1	32.5
Third phalanx	25	11.7	21.7	39.3

[a] Includes all complete specimens regardless of whether specimen is burned.
[b] Average of five specimens; all measurements are in millimeters.

values than elements of high structural density. The structural density of each skeletal element is given in Table 19.1, and the NISP values are given in Table 19.2; we summed the latter because we suspected taxonomic variation in structural density of the elements is minimal. The two variables are not correlated (rho = –.371, $p = .236$), suggesting that the overall NISP frequencies are not a function of density-mediated fragmentation and destruction. The bivariate scatterplot of these data, however, suggests that the NISP of phalanges, astragali, and calcanea may in part be a function of density-mediated processes, whereas the NISP of carpals, naviculo-cuboids, and distal fibulae are not (Figure 19.2). We return to this potentiality in our discussion of the influences of skeletal element shape on taphonomic history.

Sphericity

As indicated earlier, we suspect that as specimens approach perfect spheres in shape, they are less likely to be crushed or fragmented by sediment-overburden weight. This is because in part spheres have low surface-to-volume ratios. We used a method developed by sedimentologists (Zingg, 1935) to estimate the sphericity of the skeletal elements we studied. Sphericity is defined by the equation $[(bc/a^2)^{0.33}]$ where a is the maximum dimension (length), b is the middle-magnitude dimension (width), and c is the minimum dimension (thickness). These three measurements are taken at mutually perpendicular axes and are not related to the anatomical orientation of the bones but rather to the bone's shape. We measured these three dimensions on five complete specimens of each carpal, tarsal, and phalanx (Table 19.3), and then used the average of each dimension to calculate sphericity. Sphericity values for all elements are listed in Table 19.4. The higher the value, the greater the sphericity of the element.

Sedimentologists also use the minimum, middle-magnitude, and maximum dimensions to plot specimens on a graph to ascertain shape (Figure 19.1). Four nominal shape categories are recognized on the graph; spherical or "equant" shapes fall in the upper right

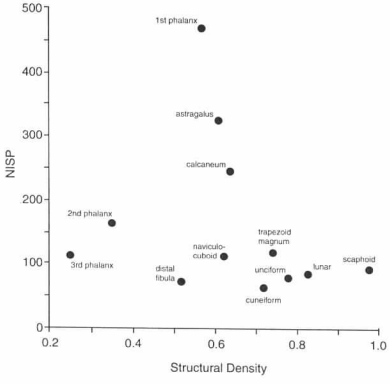

Figure 19.2 Bivariate scatterplot of NISP values per skeletal element against the structural density of each skeletal element.

quadrant; disc or "oblate" shapes fall in the upper left quadrant; blade shapes in the lower left quadrant; and rod or "prolate" shapes in the lower right quadrant (terms in quotes from Waters, 1992:27). Figure 19.1 suggests most carpals and some tarsals could be categorized as spheres whereas the calcaneum and first and second phalanges comprise rods. The third phalanx is the only blade-shaped element, and the trapezoid magnum and cuneiform are the only discs.

Recall from our discussion of skeletal element frequencies that as the structural density of phalanges, astragali, and calcanea increased, it appeared that their respective frequencies increased whereas the frequencies of carpals, distal fibulae, and naviculo-cuboids displayed no relationship to their structural density (Figure 19.2). We suspect the reason for this is that the sphericity of the latter group of elements is greater than that of the former group. As indicated in Table 19.4, skeletal elements comprising the first group are the four least spherical elements, plus the seventh least spherical element (astragalus); skeletal elements comprising the other group include the six most spherical elements plus the eighth least spherical element (cuneiform). This observation suggests that the reason for the lack of relationship between the NISP frequencies of carpals, distal fibulae, and naviculo-cuboids and their structural densities, and the apparent relationship between the NISP frequencies of phalanges, calcanea, and astragali and their structural densities, may reside in differences in the degree to which they are fragmented. As we argued earlier, we expect skeletal elements that more closely approximate spheres to be less fragmented. In other words, are phalanges,

Figure 19.3 Bighorn sheep astragali from Moses Coulee Cave. The specimen on the left is complete and undigested; the other four specimens, from left to right, display progressively greater degrees of digestive corrosion yet appear to have been ingested when complete.

Table 19.4 Sphericity Values for Skeletal Elements Examined in This Study

Skeletal Element	Sphericity
Calcaneum	0.460
First phalanx	0.499
Third phalanx	0.551
Second phalanx	0.636
Tarsal 2 + 3	0.646
Pisiform	0.676
Cuneiform	0.685
Astragalus	0.713
Scaphoid	0.735
Trapezoid magnum	0.784
Unciform	0.799
Lunar	0.800
Distal fibula	0.836
Naviculo-cuboid	0.852

calcanea, and astragali more susceptible to fragmentation because they are less spherical in shape whereas carpals, distal fibulae, and naviculo-cuboids are less susceptible to fragmentation because they are more spherical? This is the topic we turn to next.

Table 19.5 Indices of Fragmentation for All Carpals, Tarsals, and Phalanges from Moses Coulee Cave

Skeletal Element	NISP	MNE	CI%	NISP:MNE	%Whole
Cuneiform	63	63	91.4	1	80.7
Lunar	85	82	90.8	1.04	74.7
Pisiform	42	42	93.4	1	64.7
Scaphoid	93	92	90.1	1.05	72.8
Trapezoid magnum	118	118	86.9	1	71.4
Unciform	79	78	92.2	1.08	79.1
Calcaneum	247	66	32.3	3.74	7.7
Astragalus	325	230	60.6	1.41	22.3
Naviculo-cuboid	112	91	66.0	1.23	27.3
Tarsal 2 + 3	97	97	96.4	1	80.7
Distal fibula	74	74	90.5	1	64.9
First phalanx	470	197	29.4	2.39	2.1
Second phalanx	163	119	58.2	1.37	21.3
Third phalanx	113	102	57.8	1.11	22.1

Table 19.6 Indices of Fragmentation for Unmodified[a] Carpals, Tarsals, and Phalanges from Moses Coulee Cave

Skeletal Element	NISP	MNE	CI%	NISP:MNE	%Whole
Cuneiform	51	51	92.9	1	82.3
Lunar	58	57	89.3	1.02	72.4
Pisiform	27	27	94.8	1	66.7
Scaphoid	55	55	95.7	1	85.5
Trapezoid magnum	78	78	70.6	1	74.7
Unciform	59	59	93.3	1	78.3
Calcaneum	59	26	43.4	2.27	20.3
Astragalus	107	91	80.1	1.17	35.3
Naviculo-cuboid	53	50	78.2	1.06	38.2
Tarsal 2 + 3	69	69	97.7	1	84.1
Distal fibula	45	45	90.2	1	66.7
First phalanx	325	159	29.7	2.04	2.8
Second phalanx	103	71	53.2	1.45	22.3
Third phalanx	76	67	59.3	1.13	23.7

[a] Burned, gnawed, digested, and freshly broken specimens, and specimens with percussion damage, omitted.

Fragmentation

For analytical purposes, we define *modified specimens* as those that display attributes of burning, digestive corrosion, rodent or carnivore gnawing, percussion damage, or some combination of these traces of (with the possible exception of percussion) biostratinomic damage. *Unmodified specimens* are those that display none of these attributes. The three indices of fragmentation for modified and unmodified specimens combined are listed in Table 19.5. Fragmentation index values for unmodified specimens are given in Table 19.6. The CI% and %Whole values tend to increase when modified specimens are omitted, as Marean's (1991) analysis suggested they should. The majority of the NISP:MNE ratios, however, either do not change (five values) or they decrease only a small amount (six values). The single exception is the calcaneum, the NISP:MNE ratio for which decreases

Table 19.7 Absolute and Relative Abundances of Carnivore Gnawed, Digested, Rodent Gnawed, and Burned Specimens from Moses Coulee Cave[a]

Skeletal Element	Total NISP	NISP Carnivore Gnawed	NISP Digested	NISP Rodent Gnawed	NISP Burned	NISP with Percussion
Cuneiform	63	2 (3.2)	3 (4.8)	1 (1.6	6 (9.5)	0
Lunar	85	0	10 (11.8)	0	17 (20.0)	0
Pisiform[b]	42	4 (9.5)	4 (9.5)	1 (2.4	7 (16.7)	0
Scaphoid[b]	93	6 (6.5)	6 (6.5)	1 (1.1	26 (28.0)	0
Trapezoid magnum	118	6 (5.1)	7 (5.9)	0	26 (22.0)	1 (0.8)
Unciform	79	7 (8.9)	5 (6.3)	0	8 (10.1)	0
Calcaneum	247	90 (36.4)	0	1 (0.4	96 (38.9)	1 (0.4)
Astragalus	325	51 (15.7)	6 (1.8)	0	152 (46.7)	9 (2.8)
Naviculo-cuboid[b]	112	9 (8.0)	10 (8.9)	1 (0.9	38 (33.9)	2 (1.8)
Tarsal 2 + 3	97	7 (7.2)	7 (7.2)	0	14 (14.4)	0
Distal fibula[c]	74	0	4 (5.4)	0	27 (36.5)	0
First phalanx[d]	470	10 (2.1)	33 (7.0)	9 (1.9	88 (18.7)	13 (2.8)
Second phalanx	163	4 (2.5)	25 (15.3)	6 (3.7	25 (15.3)	0
Third phalanx[e]	113	5 (4.4)	3 (2.7)	15 (13.3	21 (18.6)	0

[a] Values in parentheses are relative (%) abundance of specimens with the indicated modification.
[b] One specimen displays more than one kind of modification.
[c] Two specimens display more than one kind of modification.
[d] Eight specimens display more than one kind of modification.
[e] Seven specimens display more than one kind of modification.

54% ([3.74 – 2.27] + [3.74 – 1]). This suggests that the calcaneum, the largest (Table 19.3) and also most rod-like (Figure 19.1) element, was the most prone to be fragmented if it was modified by burning, carnivore gnawing, and the like.

Thirteen first phalanx specimens, nine astragali, two naviculo-cuboids, one trapezoid magnum, and one calcaneum display percussion damage, suggesting they were broken by human predators wielding hammerstones, by roof-fall, or by a combination of the two (Table 19.7). We had intended to correlate the number of specimens displaying percussion scars with marrow and grease utility values (see below) under the assumption that larger proportions of elements with higher utility values would display such modification than elements with lower utility values if the percussion scars were the result of human taphonomic agents. The low number of specimens with percussion scars precluded calculating a coefficient, but we note that the calcaneum and first phalanx have the greatest marrow and grease values (Table 19.1), suggesting that they may have been broken for that reason. However, we also note that these are the two most rod-like elements and thus are, we suspect, the most prone to diagenetic fragmentation. Diagenetic fragmentation could account for the fact that identical relative abundances of first phalanx and astragalus specimens display percussion damage. But so could biostratonomic fragmentation account for the relative frequencies of specimens displaying percussion damage because the naviculo-cuboid, with the third highest grease utility value, has the third greatest proportion of specimens with percussion damage.

Gnawing damage by rodents may have obliterated some flake scars, though only a few specimens display such damage (Table 19.7). Part of the analytical difficulty we encountered is that some specimens were variously chewed and gnawed by carnivores, and the resulting damage could either have obliterated evidence of percussion scars or been confused with

percussion scars. Also, modern damage to bones which may have resulted from mechanical movement (the 1932 Fresno) of the sediments possibly obliterated percussion damage, though we think this unlikely given that such damage is very superficial and does not occur on many specimens. Perhaps most importantly, as we noted when we experimentally broke pig carpals, tarsals, and phalanges, not all hammerstone-broken specimens can be expected to display obvious percussion damage.

There is no statistically significant relationship between the minimum or maximum dimension of the elements (Table 19.3) and the proportion of carnivore gnawed or proportion of digested specimens ($p > .2$ for all tests); however, more than 18% of all tarsals display evidence of carnivore gnawing whereas only 5.2% of all carpals and 2.5% of all phalanges display such damage. This rank ordering is exactly the reverse for digestive corrosion: 8.2% of all phalanges, 7.3% of all carpals, and 3.2% of all tarsal specimens display digestive corrosion. It seems reasonable to suppose that larger elements are more prone to display evidence of gnawing whereas smaller elements are prone to display digestive corrosion, granting the assumption that larger elements are more difficult to ingest than smaller ones. However, as shown in Figure 19.3, astragali, the second largest skeletal element under consideration (Table 19.3), were at least occasionally ingested whole by Moses Coulee Cave carnivores and underwent various degrees of corrosive destruction as a result. This prompts us to wonder if there is a relationship between carnivore gnawing and digestive corrosion, and the food utility of the elements.

Grease and Marrow Utility

Binford (1978) determined the food value of many skeletal elements of two artiodactyls species. We chose to use caribou (*Rangifer tarandus*) index values for our analysis because this species is similar in body size and shape to the three taxa under consideration. Binford derived a grease utility value and a marrow utility value for all carpals as an articulated mass; the naviculo-cuboid, tarsal 2 + 3, and distal fibula (we believe) as an articulated mass; the isolated calcaneum; the isolated astragalus; the first phalanx; the second phalanx; and the third phalanx. We did two things to derive the marrow and grease utility values given in Table 19.1 for each isolated skeletal element. First, because all carpals, the naviculo-cuboid, tarsal 2 + 3, and distal fibula are compact bones with no marrow cavity, it is reasonable to assign them a marrow utility value of 1, which is identical to the value Binford assigned to the astragalus, a compact bone with no marrow cavity. Second, we determined the volume (via water displacement) for several complete specimens of each element and calculated the average. This was used to calculate a grease utility index value for the naviculo-cuboid, tarsals 2 + 3, distal fibula, and isolated carpals. For the three indicated tarsals, we multiplied the percent of the total volume of the three as represented by one element by the grease utility index for all three (29.87). For the six carpals, we multiplied the percent of the total volume of all six as represented by one element by the grease utility index for all six (36.47). These calculations produced the grease utility values for each individual carpal, naviculo-cuboid, tarsal 2 + 3, and distal fibula (Table 19.1).

The proportion of carnivore-gnawed specimens per skeletal element is not correlated with either the marrow utility values or the grease utility values ($p > .5$ for both). Similarly, the proportion of digested specimens per skeletal element is not correlated with these food utility values ($p > .5$ for both). Finally, we note that the correlation between the simple sum of the two utility indices and the simple sum of the proportions of gnawed and digested

Table 19.8 Correlation Coefficients (Spearman's rho) Between Fragmentation Indices and the Summed Grease and Marrow Utility Indices

	Modified and Unmodified		Unmodified Only	
Fragmentation Index	Rho	*p*	Rho	*p*
CI%	−.833	< .0001	−.773	.001
NISP:MNE	.898	< .0001	.906	< .0001
%Whole	−.749	.0021	−.688	.0065

specimens is statistically insignificant ($p = .3$). In other words, it does not seem that Moses Coulee Cave carnivores were exploiting the carpals, tarsals, and phalanges of deer-sized artiodactyls at intensities commensurate with the food value of those elements. Do the food indices have any relationship to the degree of fragmentation? In fact, they do. All three fragmentation indices, whether derived from modified plus unmodified specimens or from only unmodified specimens, are significantly correlated with the sum of the marrow and grease utility values (Table 19.8). Why might this be the case? In short, we believe this is a function of the size, shape, and density of the skeletal elements.

What Mediates Fragmentation?

According to Marean (1991:691), postburial fragmentation of bones will be indicated by small CI% values, particularly if those values are for the astragalus and naviculo-cuboid. Marean noted that he could not answer the question of how small "small" CI% values should be to unambiguously indicate postburial fragmentation. He focused on the fragmentation of what he considered to be "small, compact bones" and hypothesized that the density, size, and shape of skeletal elements would mediate their postburial fragmentation. To evaluate the influence of density on fragmentation, we correlated the three indices of fragmentation with the structural density of each skeletal element. Resulting coefficients are given in Table 19.9. If all modified and unmodified specimens (Table 19.5) are included, only the correlations between CI% and density, and between %Whole and density are significant. If only unmodified specimens (Table 19.6) are included, then all three coefficients can be considered significant ($p < .085$). This tends to corroborate Marean's suggestion that inclusion of modified specimens will skew measures of fragmentation. More importantly, the coefficients suggest that the structural density of skeletal elements mediates their fragmentation irrespective of agent and process of fragmentation.

To evaluate the influences of bone shape on fragmentation, we correlated the three indices of fragmentation with element sphericity (Table 19.4). Resulting coefficients are listed in Table 19.9. If all modified and unmodified specimens (Table 19.5) are included, only the correlation between %Whole and sphericity might be considered significant. If only unmodified specimens (Table 19.6) are included, then two coefficients, for %Whole and NISP:MNE, can be considered significant ($p < .08$). This also corroborates Marean's suggestion that inclusion of modified specimens will skew results. Focusing then on the coefficients for unmodified specimens only, the most spherical specimens tend to be least fragmented whereas the least spherical specimens tend to be most fragmented, just as we predicted. We note that this would not be apparent were only the CI% values used as measures of fragmentation.

Table 19.9 Correlation Coefficients (Spearman's rho) between Fragmentation Indices and Structural Density, Sphericity, and Size of Skeletal Elements

	Modified and Unmodified		Unmodified Only	
Fragmentation Index	Rho	*p*	Rho	*p*
		Density		
CI%	.698	.036	.601	.039
NISP:MNE	−.366	.242	−.522	.082
%Whole	.692	.013	.727	.007
		Sphericity		
CI%	.446	.11	.411	.144
NISP:MNE	−.425	.13	−.542	.045
%Whole	.513	.06	.488	.076
		Size		
CI%	−.868	< .0001	−.754	.0018
NISP:MNE	.852	.0001	.885	< .0001
%Whole	−.689	.0065	−.673	.008

Finally, to ascertain the influence of bone size on fragmentation, we correlated the three indices of fragmentation with the maximum dimension (Table 19.3) of each skeletal element. All indices of fragmentation regardless of whether unmodified and modified, or only unmodified specimens are included, correlate strongly with the skeletal element's maximum dimension (Table 19.9). In other words, larger skeletal elements tend to display higher degrees of fragmentation than smaller specimens, regardless of the measure of fragmentation. This, too, corroborates Marean's hypothesis that fragmentation is mediated by skeletal element size.

To insure that the sets of correlations in Table 19.9 are not the result of relationships between size, density, and sphericity, we correlated all possible pairs of these three variables. Only size and sphericity are correlated (rho = −.556, p = .04); density and sphericity are not correlated (rho = .35, p = .265) nor are size and density (rho = −.42; p = .174). These coefficients suggest that each variable — size, density, shape — influences fragmentation largely independently of the other two variables.

Correlation coefficients in Table 19.8 indicate that as food utility (measured as the sum of the grease and marrow utility values) of a skeletal element increases, its degree of fragmentation increases. Does the food utility of a skeletal element correlate with its size, shape, or density? As might be expected, food utility and skeletal element size are directly correlated, whether the maximum dimension (rho = .923, p < .0001) or minimum dimension (rho = .775, p = .0011) is used. In other words, as the size of a skeletal element increases, so does its food utility. The food utility of a skeletal element and its sphericity, on the other hand, are weakly and inversely correlated (rho = −.482, p = .081). This is understandable because as skeletal elements become more rod-like and less spherical in shape, their food utility increases. Finally, the food utility and structural density of skeletal elements are not correlated (rho = −.344, p = .274). We believe this results because those elements with the greatest food utility also have marrow cavities and some of the lowest structural densities.

Discussion and Conclusions

Ascertaining the effects of diagenetic fragmentation on collections of faunal remains is critical for a number of reasons. Postburial fragmentation may, as Marean (1991:677) indicates, "confound interpretations of the bone fragmenting behavior of the [bone] collector." Also, as we noted earlier, it may variously reduce the identifiability of a collection thereby influencing the NISP tallies for collections that have undergone different degrees of diagenetic fragmentation. A significant analytical hurdle for taphonomists, then, is identifying if and to what degree a collection of bones has undergone postburial fragmentation. Recognizing this fact, taphonomists have attempted to design methods for recognizing such fragmentation. Marean's (1991) efforts are the most detailed in this respect, and they are important.

Marean hypothesized that the fragmentation of skeletal elements would be mediated or influenced by their shape, size, and density. Statistically significant correlations we found between these three variables and three fragmentation indices for a single collection corroborate Marean's (1991) hypothesis. Our analysis indicates that as skeletal elements decrease in sphericity and increase in size they will also increase in food utility and, at least among the Moses Coulee Cave materials, they will have a greater tendency to be broken. It also indicates that among the carpals, tarsals, and phalanges, an element's structural density does not influence the relationship between the element's food utility and its degree of fragmentation. The significant implication in the present context, then, is that the Moses Coulee Cave bones might have been broken during the biostratinomic phase, given the correlation between the fragmentation indices and food utility (Table 19.8). The densest, most spherical, and smallest bones tend to be the least broken (Table 19.9), suggesting that if diagenetic fragmentation occurred, it was mediated by those variables.

The preceding suggests that humans seeking to extract grease and marrow broke the bones during the biostratinomic phase. Many of the Moses Coulee Cave specimens comprising fragments of carpals, tarsals, and phalanges, however, display no obvious percussion damage. But recall that when we experimentally broke carpals, tarsals, and phalanges, we found minimal percussion damage. Perhaps, then it *was* a hammerstone-wielding human who broke the Moses Coulee Cave bones, but that is not in any sense unambiguously demonstrable because the correlations we calculated indicate that there is a continuum of degrees of fragmentation among the Moses Coulee Cave assemblage of carpals, tarsals, and phalanges. Perhaps this is the result of the early twentieth century mechanical movement, mixing, and redeposition of the sediments and bones, but we find that unlikely because few of the specimens we examined display modern breaks that might be attributed to that event. Instead, we think it much more likely that the specimens we describe were fractured by both biostratinomic and diagenetic processes. The effects of biostratinomic fragmentation, in other words, were exacerbated by diagenetic fragmentation, as fragmentation during both phases was, as Marean hypothesized, mediated by the size, shape, and density of the elements.

The fragmentation continuum among the Moses Coulee Cave carpals, tarsals, and phalanges that we have documented is predictable because the skeletal elements are of varying shape, size, and density. Fragmentation also correlates with food utility, which in turn is correlated with the size and shape of the skeletal elements. Together, these observations suggest it will be no easy matter to detect postburial fragmentation because its traces mimic those of biostratinomic fragmentation. Sorting out percussion-damaged

specimens will not increase resolution because not all percussion-broken specimens display percussion damage. We conclude, therefore, that analytical efforts to sort out diagenetic and biostratinomic fragmentation must comprise more than measuring the degree of fragmentation. This does not mean that measuring the intensity and extent of fragmentation is not worthwhile. As we noted in the introduction, fragmentation influences identifiability. We would not recommend comparing taxonomic abundances of collections that were differentially fragmented. To detect differential fragmentation, fragmentation must be measured.

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