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#### **Title**

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#### **Permalink**

<https://escholarship.org/uc/item/14q2w4n9>

#### **Journal**

Journal of California and Great Basin Anthropology, 35(2)

#### **ISSN**

0191-3557

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#### **Publication Date**

2015

Peer reviewed

# Taphonomic and Metric Evidence for Marrow and Grease Production

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*Wild-game carcass processing behaviors, including marrow extraction and grease rendering, are traditionally inferred from the nutritional utility of recovered elements. The expected survivorship of bones processed for within-bone fats, as well as the inverse relationship between density and grease utility, diminishes the power to infer these behaviors by element counts alone. The palimpsests of transport and butchery decisions as well as non-human site formation processes are revealed most clearly by taphonomic and metric analysis for carcass handling and density-mediated attrition. This article presents a means of inferring ruminant marrow and grease extraction by synthesizing lines of evidence for density and bone survivorship, selectivity of marrow-rich and greasy elements, presence of percussive impact marks and fractures to fresh bone, small specimen sizes, and high fragmentation rates.*

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Traditionally, zooarchaeologists have sought to understand carcass processing choices by evaluating relative abundances of osteological elements and the nutritional contributions of these body segments. Despite a long history of using nutritional utility indices to interpret skeletal remains (see history of this topic in Diab 1998; Lupo 2001; Lyman 1992; Metcalfe and Jones 1988) there is often the problem of the equifinality of results. Further, since archaeologists can only argue from observable evidence, this approach does not consider those elements that were selected but destroyed during processing. Some processing behaviors are analytically difficult to identify due to various human taphonomic processes and density-mediated destruction which overprint behavioral signatures. Due to the palimpsests of transport and butchery decisions overwritten by non-human site formation processes, commensurate taphonomic evidence must be considered alongside relative element frequencies in order for carcass processing behaviors to be inferred.

This discussion will present a suite of basic taphonomic modifications which can aid in the identification of carcass processing behaviors, and critically consider the analytical strengths of nutritional utility indices. As an illustrative case, I present archaeofaunal data from the pre-contact residential site CA-SCL-119 in central California. This example

illustrates the potential of a synthesis of taphonomic and metric data to elucidate nutritionally-driven behavioral choices regarding marrow and grease processing.

## GREASE AND MARROW IN NUTRITIONAL PERSPECTIVE

Fats are an essential component of diet, and reliance on lean meats alone can result in severe nutritional stress, including starvation and protein poisoning (Speth and Spielmann 1982). Enloe (1993) cites marrow as a particularly important source of fat in a meat-based diet, and Morin (2007) identified marrow and unsaturated fats (including oleic acid) as vital to Nunamuit decision-making regarding carcass processing and use. The majority of fat-rich marrow in mammalian skeletons is located in elements with medullary cavities (limb bones and mandibles), yet all elements contain grease in the cancellous bone (Munro and Bar-Oz 2005). While ungulates vary seasonally in the amount of meat fat they contain (Brink 1997; Speth 1990), marrow and grease have been shown to be a reliable, rich source of fat in any season (Bar-Oz and Munro 2007). The metabolization of fat is a complex process—e.g., fat is mobilized in proximal elements before distal ones in some species, and opposite in others (Morin 2007)—yet within-bone fat is last in the fat-mobilization sequence of most animals (Brink

1977; Outram 2001). For this reason, within-bone fats are a dependable and important nutritional source during winter months and stressful periods (Outram 2001).

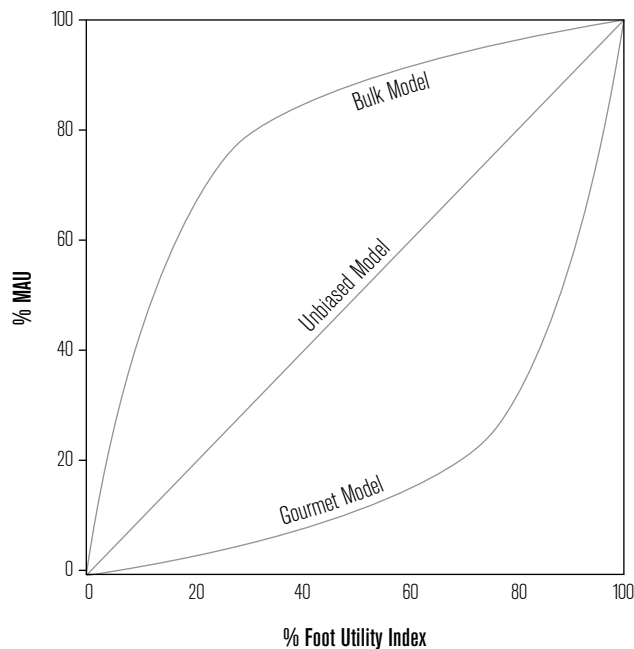
Elements processed for marrow extraction are cracked open along the diaphysis of the limb bone or ramus of the mandible. The debris from such processing is often highly fragmented, although the number of shaft fragments relative to articular ends varies depending upon the method of breakage (Binford 1978). This behavior is expected to inflate NISP (number of identified specimens) values for an element up to the point beyond which heavy fragmentation would result in unidentifiable specimens (Grayson and Delpech 1998). Fragmentation of the bone during marrow removal can potentially reduce bone representation by decreasing the visibility of anatomically and taxonomically diagnostic features, and by exposing more surface area to destruction by post-depositional processes (Munro and Bar-Oz 2005:224). Some fragments bear taphonomic marks of percussive impacts, and all contain edges that display fracture morphologies characteristic of fresh bone (Bar-Oz and Munro 2004; Johnson 1985). Since it is only necessary to break the shaft enough to extract the marrow from its cavity, the resulting fragment size is unrelated to the efficiency of this action (Wolverton et al. 2008).

Grease extraction is the last and most destructive of butchering events (Brink 1997). Grease requires more work to render than marrow, and involves fracturing—often pulverizing—bone into smaller fragments (Wolverton 2002; Wolverton et al. 2008) and boiling the fragments. Boiling bone fragments extracts lipids along with other fat-soluble trace nutrients, and the process is most efficient for fragments 1–5 cm. in size (Church and Lyman 2003). The added work to extract grease leaches more nutrients from a carcass, and the product may be stored up to three years (Munro and Bar-Oz 2005). Ethnoarchaeological studies (Binford 1978; Yellen 1991) noted that elements used to render grease were often those previously processed for marrow, with the emphasis on a further breaking down of the spongy bone of epiphyses. It is also unlikely that grease rendering would be undertaken for limb bones if marrow processing was skipped (Outram, 2001). These successive processing behaviors produce archaeological debris from which it is difficult to discern processing decisions solely through element frequencies.

## ZOOARCHAEOLOGICAL APPROACHES TO CARCASS PROCESSING

Zooarchaeologists commonly compare nutritional utilities, or measures of calories, meat, marrow, and grease, with respective skeletal element frequencies to interpret carcass processing decisions. The approach originally stemmed from Binford's (1978) "economic anatomy" approach to quantification of nutritional utility of body segments. Rather than identify carcass processing decisions solely, Binford's motivation was to understand Paleolithic site functions using actualistically-derived measures that he could transfer from contemporary contexts to prehistoric sites. Following this seminal work, many others have published data on various animals' body-part nutritional utility and used these data to interpret carcass processing (e.g. Bar-Oz and Munro 2007; Borrero 1990; Brink 1997; Diab 1998; Emerson 1990; Friesen 2001; Lyman 1994a; Madrigal and Holt 2002; Metcalfe and Jones 1988; Morin 2007). As pointed out by Wolverton (2002), the *a priori* assumption of many utility analyses is that body segments with the highest return rates of nutrients and calories will be preferentially selected and processed. Ideally, if body segments were selected according to their nutritional return, correlations between element abundance and utility would reflect an increasing monotonic relationship. This relationship may take the shape of any one of the utility strategies described by Binford (1978): *unbiased* selection of elements in proportion to their utility, *bulk* selection maximizing the use of all but the lowest utility elements, or *gourmet* selection of only the very highest utility elements (Fig. 1).

Given the argument that element abundances and utility indices should be treated as ordinal scale measures (Faith and Gordon 2007; Grayson 1984; Lyman 2008; Morin 2007), a conservative analysis of their relationship would employ a non-parametric rank-order correlation using Spearman's rho statistic. However, the utility curves described in Figure 1 must be analyzed in interval-scale terms. Rank correlations essentially "flatten" a utility curve, resulting most readily in a positive, negative, or uncorrelated relationship between the variables. In this case bulk, unbiased, and gourmet strategies all produce similar correlation results as long as the ranking, rather than the values, of the points in the *x*-axis and *y*-axis directions do not change. Faith and Gordon (2007) proposed a method to circumvent the inability



**Figure 1. Hypothetical utility strategies of bulk, unbiased, and gourmet selectivity. Adapted from Binford 1978.**

of rank order correlations to discern interval-scale utility strategies by combining correlations with measures of skeletal part evenness. This approach may work in some settings to identify transport decisions and carcass selection for general food utility or even meat utility, but it has limited utility when describing contexts in which people intensively processed within-bone fats. Outram argues that within-bone fats are “very unlikely to be ignored by peoples under any degree of subsistence stress” (2001:401) and that energy, time, and fuel for grease extraction would be expended only when within-bone fats are needed. This carcass processing approach does not discriminate particular elements according to the gourmet, unbiased, or bulk strategies.

While these analyses of carcass utility are the main approaches used by zooarchaeologists to date, there are methodological problems in their application to case studies in which intense bone processing for within-bone fats is suspected. For three main reasons, the behaviors of marrow and grease processing may result in analytical ambiguity or equifinality when explored primarily through rank-order correlations between element abundance and utility. First, Brink argued that grease production in some cases destroys archaeofaunal elements so thoroughly that one may expect a “negative, not a positive, relationship

between the variables of [element] abundance and food [grease] value” (1997:272). For those cases in which bones are fragmented but not pulverized, there may be a reduction in element identifiability but not an elimination of data. Many have noted that measures of fragmentation (e.g., NISP/MNE [minimum number of elements]) as well as abundance (e.g., NISP and MNI [minimum number of individuals]) are themselves measures of identifiability for analysts (Cannon 2013; Marshall and Pilgram 1991, 1993; Nagaoka 2005). Second, if marrow extraction preceded grease rendering, the subsequent bone fragmentation and destruction may erase evidence of earlier marrow processing. Finally, density-related taphonomic processes are expected to bias archaeofaunal assemblages such that grease processing would be indiscernible solely by utility indices. Grease utility values and debris from destructive culinary processing generally vary inversely with bone density (Brink 1997; Lupo 2001; Lyman 1985). Further, destruction of low-density elements during grease rendering may mimic the effects of other taphonomic agents on an assemblage.

Lyman (1985, 1992) questioned the basic premise that element abundances reflect human use and discard patterns without alteration by taphonomic processes. Many other scholars have argued that various taphonomic and metric data must accompany inferential arguments mobilizing utility analyses of marrow and grease values (e.g., Brink 1997; Diab 1998; Munro 2004; Munro and Bar-Oz 2005; Outram 2001; Waguespack 2002; Wolverton 2002). In this paper I explore several zooarchaeological signals of marrow and grease processing: correlations between element quantities and both utility and bone mineral density, taphonomic marks associated with dynamic loading, and element fragmentation.

### FAUNAL EXPECTATIONS FOR MARROW AND GREASE PROCESSING

Despite the aforementioned problems with the statistical validity and interpretive power of utility correlations, this method is still the most common tool for understanding carcass processing. Generally, food utility indices are used to evaluate decisions of element *transport* from a kill site and *field butchering* (e.g., Metcalfe and Jones 1988) rather than intensive processing for extracting within-bone fats in later stages of carcass processing. Correlations between

Table 1

## FAUNAL EXPECTATIONS FOR MARROW AND GREASE PROCESSING

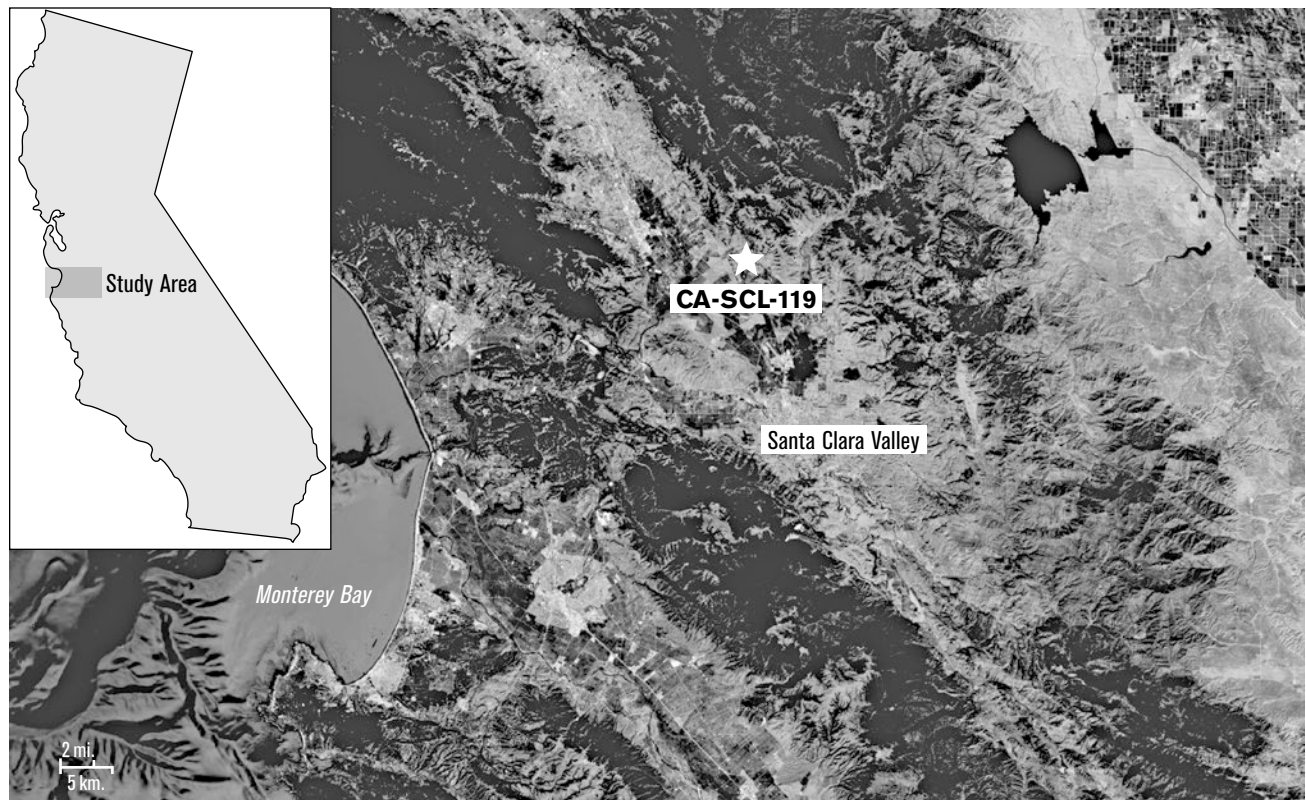
Processing Activity	Variables to test for correlation	Interpretation of Correlation Results
Marrow extraction	Element count (NISP, MNE), marrow yield	Positive → more elements of high marrow yield are selected for transport and processing
	Fragmentation (%whole), marrow yield	Positive → highest fragmentation for marrow-rich elements (especially cortical shafts)
	Fragmentation, frequency of fresh fractures	Positive → the most fragmented elements will have the highest quantities of fresh fractures from human processing
	Freq. fresh bone fractures, marrow yield	Positive → elements with the highest marrow yield have the most fractures on fresh bone
	Presence of percussive impacts, marrow yield	Positive → elements with the highest marrow yield will preferentially show percussive impact marks
Grease rendering	Element count (NISP, MNE), density	Positive → processing of low-density elements for grease extraction appears as density-mediated attrition
	Fragmentation (NISP/MNE), element count (%MAU)	Negative → Elements selected for processing will show both high counts as meat portions and high levels of fragmentation (especially cancellous ends)
	Maximum dimension, grease yield	Negative → grease-rich elements have the lowest max dimensions from pulverization in processing
	Maximum dimension, frequency of fresh fractures	Negative → grease processing of small fragments already processed for marrow should have more fresh fractures for small fragment sizes

element counts and marrow yield—rather than meat yield—may suggest differential *secondary processing* of high-yield marrow bones rather than initial transport decisions (Madrigal and Holt 2002) if supported by taphonomic evidence. The variables proposed for consideration alongside element counts include utility, bone mineral density, percussive impact marks, evidence for fracture on fresh bones, fragmentation rates, and maximum dimension. Inferences of marrow and grease processing are based on expected correlations among these variables (Table 1).

Marrow extraction is reflected by higher indices of fragmentation (measured by completeness of marrow-bearing elements) and lower survivorship than non-marrow bearing bones, as well as by correlations among marrow yield, frequency of fractures to fresh bone, and fragmentation (Marshall and Pilgram 1991; Munro 2004; Nagaoka 2005; Wolverson 2002; Wolverson et al. 2008). Overall it is expected that marrow extraction would result in a greater extent of fragmentation of cortical shafts, although not necessarily intensity of fragmentation (Lyman 1994b; Nagaoka et al. 2008; Wolverson 2002; Wolverson et al. 2008). Outram (2001) avoids equifinality by integrating data on levels of fragmentation, types of bone fragmented, levels of fresh fracture, and evidence for deliberate fracture and post-depositional fragmentation. Other approaches focus

on the intensity of marrow extraction: differentiating evidence for incidental marrow consumption at meals and specialized, intensive processing of marrow (Enloe 1993), extraction from less marrow-rich parts of a carcass (Bar-Oz and Munro 2007), and extraction from juvenile animals in a population (Munro and Bar-Oz 2005).

Grease extraction is indicated by a greater intensity of fragmentation, measured by a high NISP/MNE ratio and small specimen size, and fragmentation targeted at the cancellous ends of long bones (Lyman 1994b; Nagaoka 2005; Nagaoka et al. 2008; Wolverson 2002; Wolverson et al. 2008). This may be seen as a negative correlation between fragmentation rates and the survivorship of grease-rich elements (measured by %MNI), since processed elements are expected to be fragmented and have a lower survivorship (Munro and Bar-Oz 2005). Church and Lyman (2003) experimentally showed that bone used for rendering grease should generally measure less than 5 cm. in maximum dimension, so an inverse relationship between maximum dimension and grease utility may signal this activity. One must consider the ways in which element abundance patterns are the result of both fragmentation and taphonomic effects on different bones' durabilities. Due to the relationship between element density and grease utility, one would expect density-mediated attrition to be reflected by positive correlations between element abundance and bone



**Figure 2.** Map of site CA-SCL-119 and surrounding area.

mineral density (Lyman 1985). However, if taphonomic biases destroyed most of the low density specimens, it is possible that many markers of human economic decisions may be overprinted by this destruction.

Overall, it is expected that marrow processing would be indicated by *selectivity of marrow-rich elements* (unless this is overwritten by subsequent processing); *extensive fragmentation* of long bone shafts; and *numerous taphonomic markers* of percussive impacts and fractures to fresh bone. Grease processing would be indicated by *selectivity of greasy elements* (unless this is overwritten by bone comminution); *high intensity of fragmentation* rates of cancellous long bone ends; generally *small specimen sizes*; and recovery primarily of *high-density specimens* resulting from destruction of low-density elements.

#### **CENTRAL CALIFORNIA CASE STUDY: CA-SCL-119 ARCHAEOFAUNAL SAMPLE**

To give an example of assessing an archaeofaunal sample with the expectations listed above, I present a case study from the multicomponent residential site of CA-SCL-119

in central California's southern Santa Clara Valley (Fig. 2). The site of CA-SCL-119 was primarily investigated by the California State Department of Transportation (CalTrans) and Far Western Anthropological Group, Inc. during the 1991 California Highway 152 rehabilitation project in the southern Santa Clara Valley (Hildebrandt 1997; Hildebrandt and Mikkelsen 1993). The residential site preserves numerous midden features, house floors, hearths, and burials from the Early through Late periods. The periods of interest in this analysis include the Middle Period (600 B.C.–A.D. 1000) and Middle-Late Transition (MLT, A.D. 1000–1250). Five spatially discrete loci comprise the site, and within each locus Late Holocene component areas were defined based on the radiocarbon dating of shell and charcoal, soil stratigraphy, and obsidian hydration analysis (Hildebrandt and Mikkelsen 1993). The clear temporal affiliation of the components allows the archaeofaunal sample from each to be treated as a distinct analytical assemblage in this study.

Archaeofaunal assemblages from two occupational components (Middle NISP=2,062, MLT NISP=1,044) are examined to address ruminant carcass processing

through time. The total ruminant specimen counts by period are Middle=673, MLT=345. Despite reasonable NISP values for these assemblages, derived counts of MNE and MNI are low for the most common taxa such as medium ruminants. Analysis of each component's handling of ruminants, by element count and taphonomic modifications, illustrate the value of a multivariate approach to carcass processing.

## METHODS

Only taxa collected from the Middle and MLT components are considered here, with an emphasis on the dominant large game: mule deer (*Odocoileus hemionus*) and elk (*Cervus canadensis*). Smaller-bodied prey such as cottontail rabbit (*Sylvilagus* sp.), pocket gopher (*Thomomys talpoides*), coyote (*Canis latrans*), Western gray squirrel (*Sciurus griseus*), and California ground squirrel (*Spermophilus beecheyi*) figure prominently in the assemblages. Other common prey includes ducks (*Anas* sp.), geese (*Chen* sp.), gulls (*Larus* sp.), Sacramento perch (*Archoplites interruptus*), freshwater turtle (Emydidae), and frogs and toads (Anura).

The assemblages were recovered by dry screening through 1/4-inch and 1/8-inch mesh and collecting all observed bones (Hildebrandt and Mikkelsen 1993). Taxonomic and element identifications were made using comparatives from the University of California, Santa Cruz, anthropology and osteology collections; the University of California, Berkeley Museum of Vertebrate Zoology ornithology and mammalogy collections; and the California Academy of Sciences. Less identifiable specimens were assigned to body segment and class (e.g., Mammalia, Aves), and to the general size class of very large (i.e., elk), large (i.e., deer, male pinnipeds), medium (i.e., terrestrial carnivores, female pinnipeds), and small (i.e., leporids, rodents) taxa. Following Outram (2001), indeterminate fragments that could not be assigned to specific element and taxon were assigned to size and bone type and recorded for weight and taphonomic modifications. Shaft fragments were coded by the presence of specific zones (i.e., proximal, medial, distal) or diagnostic features and taxon.

Modifications noted included cut marks, chops, impact notches, counterblow marks, anvil damage, rodent gnawing, root-etching, and bone tool modifications

(Fisher 1995); fractures on fresh or weathered bones (Johnson 1985); burn modifications and color (Shipman et al. 1984); and carnivore modifications (Binford 1981). The frequencies of impact notches, counterblow marks, and anvil damage are considered together in this analysis as percussive impact marks. Ruminant bone mineral density (BMD) was recorded by identifying the scan sites present on a specimen and recording the associated bone mineral density using Lam et al. (1999:351–353; see also Lam et al. 2003). Metrics include maximum dimension (nearest cm.) and weight (nearest 0.1 g.).

Taxa and body part quantities were derived following the methods of Klein and Cruz-Urbe (1984; see also Grayson 1984, and Reitz and Wing 1999). Counts for overall “ruminants” total the deer, elk, and large to very large ruminant fragments, since it is expected that all wild ruminants at this site were handled similarly in the carcass processing stage. Numbers of specimens (NISP) were calculated for each species and indeterminate ruminant size categories. Normed NISP (NNISP) values were calculated by dividing the total fragments per element by the number of times the element is represented in the body (Fisher 2010; Grayson and Frey 2004). Taphonomic marks per element (modifications of each type per element category) are given by %NISP.

Minimum individual (MNI) counts considered portion, symmetry, age, and context (Reitz and Wing 1999). Minimum elements (MNE) per taxon were recorded by two methods: by whole element considering portions and symmetries along with age (immature, adult), and by portions of elements (proximal, distal, shaft) considering symmetries and age. For this study minimum counts of epiphyseal portions stood the best chance of not implicating specimen interdependence and thus meeting assumptions of statistical tests (Grayson 1984). However, since fragmentation for shafts versus epiphyseal portions is expected to be structured by marrow versus grease processing, MNE counts by portion were calculated for long bone elements.

The percentage of whole (%whole) marrow-bearing elements was used to infer the extent of fragmentation, while the ratio of total fragments per element (NISP divided by MNE) was used to estimate fragmentation intensity (Wolverton 2002; Wolverton et al. 2008; see also Marshall and Pilgram 1991; Nagaoka 2006; Nagaoka et al. 2008). Specimen size (average length)

was used as an absolute measure of fragmentation. Although other measures of fragmentation are possible, including average percent of total scan sites per specimen and portions of elements represented by a specimen (Nagaoka et al. 2008), those methods were not employed here due to small fragment sizes.

As a measure of element counts reflective of meat portions, a “minimum animal unit” (MAU) was calculated for those bone groupings for which ruminant utility values are reported (e.g., C3-7 were lumped together, as were all thoracics, all lumbar, and all ribs). Finally, the MAU statistic was standardized:  $\%MAU = (MAU / (MAU / (\text{highest MAU value})) \times 100$  (after Binford 1978, 1981). For grouped categories (e.g., radio-ulna, tibia-tarsals, atlas-axis, pelvis-sacrum, metacarpals-carpals) the highest %MAU for each group was recorded. Since the assemblage sample sizes varied, %NISP and %MAU were used to compare presence of skeletal portions and rate of taphonomic marks per element (total modifications of each type per element category) to compare human and carnivore modifications.

Rank order correlations test whether utility predicts element selection and density predicts specimen survivorship (Grayson 1989; Lyman 1985, 1994a). Utility analyses could be completed with NISP (Marshall and Pilgram 1991) but biases of fragmentation and interdependence are avoided by %MAU or NNISP (Grayson 1984; Reitz and Wing 1999). Since %MAU was calculated to test correlations between body part representation and utility, element data were grouped in this statistic to mirror element clustering of nutritional values; for example, by including “riders” in butchery units (Binford 1978). Utility values include grease (Binford 1978:73; Manne et al. 2012:93); marrow (Madrigal and Holt 2002:749, 751); meat weight, kilocalories, meat return rate (Madrigal and Holt, 2002:749, 751; Manne et al. 2012:93); and a general food utility index (FUI; Metcalfe and Jones 1988:498). Finally, to explore how element fragmentation varies by utility, NISP/MNE and average maximum dimension were compared to grease and marrow values.

## RESULTS

### *Carcass Transport and Modifications*

Ruminant counts at CA-SCL-119 include NISP of deer (Middle = 213, MLT = 94), elk (Middle = 216, MLT = 75),

and overall ruminant specimens (Middle = 244, MLT = 179). The processing of ruminant carcasses and comminution of specimens resulted in low MNI counts per species: deer Middle = 3, MLT = 2; elk Middle = 5, MLT = 2. Proportions of deer elements (%NISP) identifiable to body segments decrease through time for crania (Middle = 8.7%, MLT = 2.3%,  $Z = 2.06$ ,  $\rho < 0.05$ ) and axial skeletons (Middle = 21.7%, MLT = 12.8%,  $Z = 1.83$ ,  $\rho = 0.07$ ) while the appendicular skeleton increases proportionally over time (Middle = 69.6%, MLT = 84.8%,  $Z = -2.81$ ,  $\rho < 0.01$ ). This may be due to either diachronic shifts in carcass transport from kill sites or increased fragmentation of long bones, and thus inflated NISP values, in the MLT component. The elements likely represent some initial and mostly secondary butchery in both periods.

### *Density-Mediated Attrition*

Many taphonomic processes—including trampling, weathering, carnivore gnawing, and grease rendering—most heavily affect skeletal elements or parts of elements with low bone mineral density (BMD; Lyman 1994a). Positive rank-order correlations between ruminant element portion abundances (NNISP, by presence of BMD scan sites) and density for deer suggest density-mediated attritional processes likely impacted element abundance patterns, but not to a statistically significant degree (Middle:  $r_s = 1.83$ ,  $\rho = 0.08$ ; MLT:  $r_s = 0.18$ ,  $\rho = 0.3$ ). Since the cause of this possible attrition is not clear from this correlation alone, further taphonomic evidence for human and non-human modifications must be assessed.

### *Carcass Processing and Utility Indices*

Rank order correlations for the Middle Period assemblage suggest ruminant elements positively vary with marrow and meat return rates and deer grease, while elk grease and deer meat weight and calories are negatively correlated. Deer and overall ruminant elements show a positive, strong correlation with grease and marrow in the MLT Period (Table 2). The relationship between element utility and counts potentially reflects increasing specialization of carcass processing. There is no correlation between total ruminant counts and grease in the Middle Period, yet a strong correlation exists between these (using either counting method %NNISP or %MAU) in the MLT Period sample. This



**Table 2**

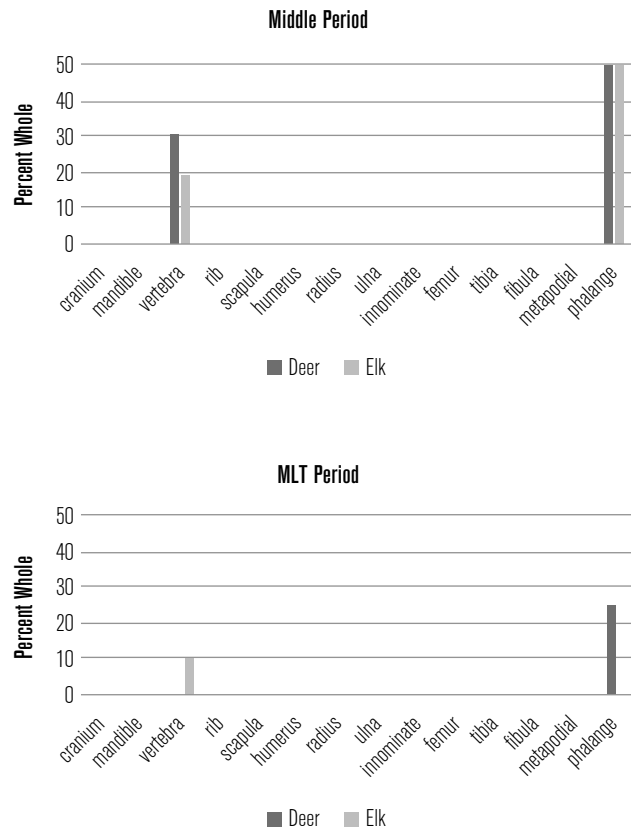
**SPEARMAN'S RANK ORDER CORRELATIONS  
BETWEEN RUMINANT ELEMENT COUNTS  
(%MAU OR %NNISP) AND UTILITY INDICES**

Component and Variables	Correlation	
	$r_s$	$\rho$
<b>Middle Period</b>		
Grease & Deer %MAU	0.64	<0.01
Marrow (kcal/hr) & Deer %MAU	0.53	<0.05
Marrow (kcal/hr) & Deer %NNISP	0.46	<0.05
Kcal & Deer %NNISP	-0.72	<0.05
Meat wt. & Deer %NNISP	-0.72	<0.05
Grease & Elk %NNISP	-0.47	<0.05
Meat + marrow & Elk %MAU	0.53	0.05
Marrow (kcal/hr) & Ruminant %NNISP	0.43	0.05
<b>MLT Period</b>		
Grease & Deer %MAU	0.56	<0.05
Marrow (kcal/hr) & Deer %MAU	0.47	0.05
Marrow (kcal/hr) & Deer %NNISP	0.48	<0.05
Grease & Ruminant %MAU	0.44	<0.05
Grease & Ruminant %NNISP	0.49	<0.05
Marrow (kcal/hr) & Ruminant %NNISP	0.46	<0.05

pattern may emphasize the value of considering less identifiable specimens—or those identifiable to ruminant body segments but not particular species—since these specimens may be associated with comminution for grease or marrow processing and are thus vital to interpretation of processing behaviors. While the observed positive relationships may show some level of selectivity for grease-rich or marrow-rich elements, the fragmentation of elements (especially cortical shafts versus cancellous ends) and patterns in taphonomic or metrics data can further clarify whether there was processing for these within-bone fats.

*Fragmentation Indices*

By distinguishing fragmentation extent (measured by %whole) and intensity (measured by NISP/MNE and size), one may infer diachronic shifts in within-bone fats processing (marrow and grease, respectively). Figure 3 shows the percent of whole ruminant elements in each period, and illustrates the low degree of completeness of marrow-bearing elements in both periods. Since the degree of whole elements for most ruminant specimens



**Figure 3. Percentage of whole deer and elk elements by period.**

is 0% for both periods (Table 3), the assemblage has a very low completeness index, which suggests extensive marrow processing.

Along with a high extent of fragmentation across marrow-bearing elements (low %whole), the ratio of specimens per element (NISP:MNE) shows high intensity of fragmentation for both diaphyses and epiphyses of long bones (Fig. 4). The intensity of fragmentation is higher for shafts than epiphyses. From the Middle to MLT Periods there is a shift to lower shaft fragmentation yet similar epiphysis fragmentation, although some elements were not identified in the MLT assemblage (Table 4).

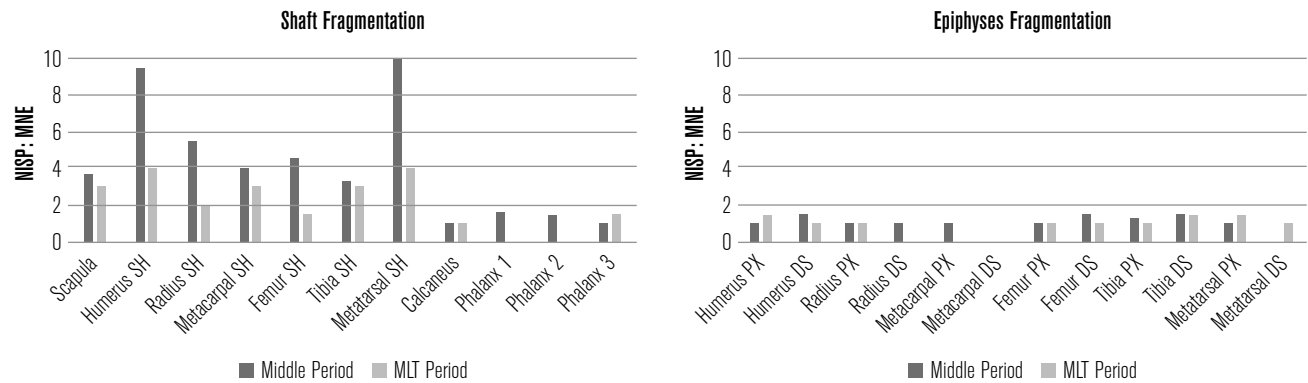
Fragmentation extent refers to how much of an assemblage is actually fragmented (%whole), while intensity of fragmentation (NISP:MNE) and maximum dimension consider the degree to which an element was fragmented. Specimens that could not be assigned to elements do not contribute to some fragmentation indices (NISP/MNE or %whole), yet maximum

**Table 3**

**FRAGMENTATION (%WHOLE) OF RUMINANT ELEMENT PORTIONS BY PERIOD**

Element	Deer Middle			Deer MLT			Elk Middle			Elk MLT		
	CO	NISP	%CO	CO	NISP	%CO	CO	NISP	%CO	CO	NISP	%CO
cranium	0	8	0	0	1	0	0	3	0	0	1	0
mandible	0	10	0	0	1	0	0	13	0			
vertebra	4	13	30.8	0	3	0	12	62	19.4	1	10	10
rib	0	32	0	0	8	0	0	53	0	0	23	0
scapula	0	3	0	0	2	0	0	5	0	0	1	0
humerus	0	14	0	0	9	0	0	9	0	0	2	0
radius	0	15	0	0	3	0	0	4	0	0	2	0
ulna	0	2	0	0	3	0	0	2	0			
innominate	0	23	0	0	9	0	0	15	0	0	2	0
femur	0	8	0	0	4	0	0	5	0	0	2	0
tibia	0	12	0	0	9	0	0	4	0	0	4	0
metapodial	0	28	0	0	19	0	0	7	0	0	3	0
phalange	3	6	50	1	4	25	4	8	50	0	1	0

Note: CO=count of complete specimens; NISP=total specimens per element; %CO=percent complete per element

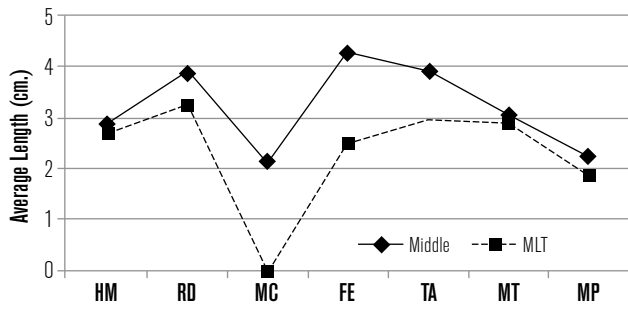


**Figure 4. Fragmentation (NISP/MNE) of ruminant element portions by period**

**Table 4**

**FRAGMENTATION (NISP/MNE) OF RUMINANT ELEMENT PORTIONS BY PERIOD**

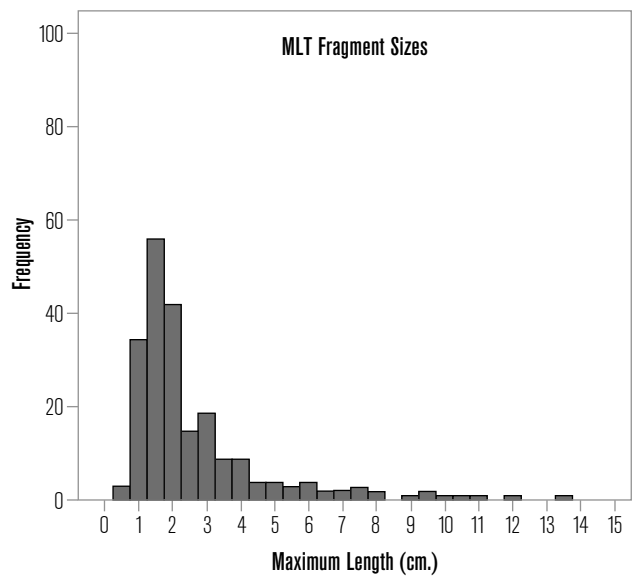
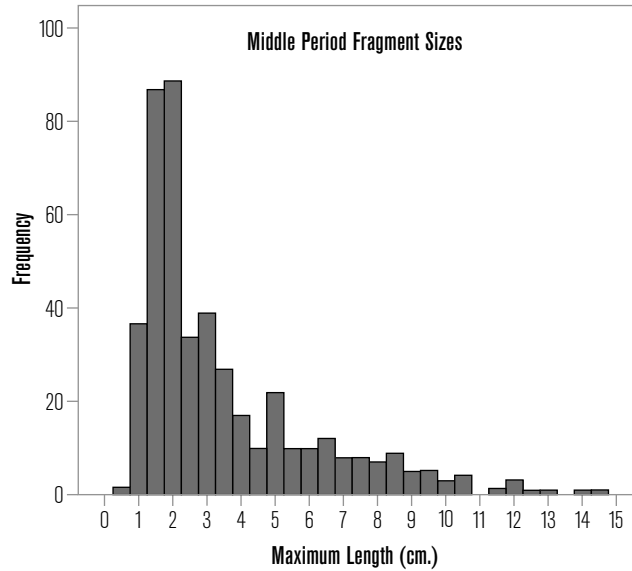
Element	Marrow Index	Middle: NISP/MNE	MLT: NISP/MNE	Element	Grease Index	Middle: NISP/MNE	MLT: NISP/MNE
Scapula	6.40	3.67	3.0	Humerus PX	75.46	1.00	1.50
Humerus SH	29.01	9.50	4.0	Humerus DS	27.84	1.50	1.00
Radius SH	54.87	5.50	2.0	Radius PX	37.56	1.00	1.00
Metacarpal SH	64.38	4.00	3.0	Radius DS	32.70	1.00	0.00
Femur SH	41.46	4.50	1.5	Metacarpal PX	16.71	1.00	0.00
Tibia SH	68.34	3.33	3.0	Metacarpal DS	42.47	0.00	0.00
Metatarsal SH	90.87	10.00	4.0	Femur PX	26.90	1.00	1.00
Calcaneus	21.19	1.00	1.0	Femur DS	100.00	1.50	1.00
Phalanx 1	30.00	1.60	0.0	Tibia PX	69.37	1.33	1.00
Phalanx 2	22.15	1.50	0.0	Tibia DS	26.05	1.50	1.50
Phalanx 3	1.00	1.00	1.5	Metatarsal PX	17.88	1.00	1.50
				Metatarsal DS	43.13	0.00	1.00



**Figure 5. Profile of specimen dimensions for Middle and MLT periods. Abbreviations: HM = humerus, RD = radius, MC = metacarpal, FE = femur, TA = tibia, MT = metatarsal, MP = metapodial.**

dimension metrics consider these less identifiable specimens. It is expected that marrow extraction would produce moderately-sized fragments and grease extraction would produce many, smaller fragments. A skeletal profile of specimen size by component shows the smaller maximum dimension of MLT limb elements which are expected to be targeted for marrow processing (Fig. 5). Overall, fragmentation rates suggest ribs, innominates, metapodials, humeruses, and femurs are highly fragmentary, while the maxillas, mandibles, sacrums, and small, dense bones of the manus and pes (carpals, tarsals, and sesamoids) are the least fragmented.

Approximately half of the Middle Period ruminant sample is 1.5–4.5 cm. in maximum dimension, while half of the MLT specimens are 1.5–3 cm. in length (Fig. 6). Metrics of average maximum dimension between components for deer (Middle = 2.73, MLT = 2.32;  $t=1.999$ ,  $df=233.8$ ,  $\rho < 0.05$ ) and elk (Middle = 5.24, MLT = 4.62;  $t=1.493$ ,  $df=241$ ,  $\rho=0.14$ ) suggest that specimens are smaller and more fragmented in the MLT component. The maximum dimension of all ruminant specimens suggests that fragments from the Middle Period sample are generally larger and less uniform in size ( $M=3.48$ ,  $SD=3.59$ ) than the MLT sample ( $M=2.70$ ,  $SD=2.18$ ). The greater fragmentation and constrained, smaller sizes (0–2 cm. for many ruminant specimens) in the MLT is likely a result of grease rendering that was more efficient and required shorter boiling times (Church and Lyman 2003). Overall, fragmentation indices show a pattern of extensive marrow extraction, reflected in low %whole of marrow-bearing elements, and intense grease processing, indicated by high NISP:MNE ratios and small fragment sizes.



**Figure 6. Maximum dimension of ruminant fragments from the Middle and MLT periods.**

*Fragmentation and Taphonomic Modifications*

The high degree of fragmentation and low specimen sizes were analyzed with respect to utility values and taphonomic modifications. Maximum dimension (cm.) is negatively correlated with marrow and grease values for Middle Period ruminants (Table 5). Ruminant specimens from the Middle component also show strong negative correlations between maximum dimension (cm.) and frequencies of fresh fractures or percussive impact marks. Overall, these results suggest that high

Table 5

## RANK ORDER CORRELATIONS AMONG TAPHONOMIC MARKERS AND UTILITY INDICES FOR EACH PERIOD

Variables	Middle						MLT					
	Deer		Elk		Ruminant		Deer		Elk		Ruminant	
	$r_s$	$\rho$	$r_s$	$\rho$	$r_s$	$\rho$	$r_s$	$\rho$	$r_s$	$\rho$	$r_s$	$\rho$
NISP/MNE, Grease	-0.16	0.61	0.02	0.94	-0.01	0.99	-0.22	0.49	0.51	0.09	0.03	0.92
NISP/MNE, Marrow	0.65	<0.05	0.30	0.36	0.64	<0.05	0.55	0.08	0.22	0.55	0.44	0.17
NISP/MNE, %MAU	-0.00	0.99	-0.29	0.21	-0.23	0.32	0.29	0.25	-0.17	0.51	0.22	0.34
NISP/MNE, Fresh fractures	0.29	0.20	-0.01	0.95	0.40	0.08	0.35	0.12	0.29	0.21	0.75	<0.01
Fresh fractures, Grease	0.63	<0.01	0.50	<0.05	0.65	<0.01	0.67	<0.01	-0.09	0.69	0.48	<0.05
Fresh fractures, Marrow	0.53	<0.05	0.51	<0.05	0.58	<0.01	0.47	<0.05	0.18	0.43	0.47	<0.05
Percussive impacts, Grease	0.66	<0.01	0.74	<0.01	0.83	<0.01	0.62	<0.01	-0.22	0.35	0.49	<0.05
Percussive impacts, Marrow	0.28	0.23	0.43	0.05	0.51	<0.05	0.42	0.06	-0.17	0.46	0.31	0.17
Max length, Grease	-0.35	0.12	-0.39	0.08	-0.80	<0.01	-0.08	0.74	0.24	0.31	-0.06	0.81
Max length, Marrow	-0.16	0.49	-0.11	0.63	-0.46	<0.05	-0.04	0.88	-0.06	0.79	-0.15	0.51
Max length, Fresh fractures	-0.13	0.56	-0.16	0.48	-0.48	<0.05	0.21	0.35	0.41	0.06	0.30	0.18
Max length, Percussive impacts	-0.04	0.88	-0.22	-0.53	-0.53	<0.05	0.26	0.24	0.33	0.14	0.35	0.11

fragmentation, fractures on fresh bone, and percussive impact marks contributed to small maximum dimensions of elements that were likely processed for marrow and then grease. The correlations of taphonomic markers and size with grease utility may reflect this later stage of processing. Further, the crushing of bone to render grease more efficiently (Church and Lyman 2003) possibly overprinted some previous signatures of marrow extraction and bias against the identification of debris from grease-production to particular species or elements. This latter point is a possible explanation for the negative relationship between grease values and Middle Period elk fragmentation, given the taphonomic and metric evidence for within-bone fat processing. Examination of overall taphonomic modifications, regardless of the identifiability of a specimen to a particular skeletal element, is expected to clarify these palimpsests of carcass processing.

In both periods, there is a high degree of fragmentation (shown by low %whole) and intensity (shown by high NISP/MNE) of ruminant element portions. Since many fragmentation extent (%whole) values are zero (see Appendix A-1), this index was not statistically compared with utility indices. Although it is a measure of fragmentation intensity (and thus grease processing), it is interesting that NISP/MNE values positively correlate with marrow indices (Table 3). Grease values negatively correlate with fragmentation in the Middle Period, and positively in the MLT (Table 3). Rank order correlations

between elements' utility and frequency of taphonomic modifications further illustrate the fragmentation and modification effects on specimens (Table 3). Frequencies of fractures on fresh bone and percussive impact marks both significantly correlate positively with marrow and grease utility. These results suggest that specimens of high marrow and grease utility, when identifiable to element, showed evidence of percussive impacts on fresh bone for marrow extraction and were highly fragmented for grease rendering.

Since processing behaviors may negatively affect the number of specimens which can be confidently assigned to a particular species, taphonomic modifications of less identifiable fragments (e.g., long bone diaphyses and epiphyses, vertebrae, and metapodials) can shed light on processing behaviors. Analysis of specimens with evidence of burning, carnivore gnawing, cut marks, fresh bone fractures, and percussive impact marks shows some diachronic shifts in ruminant handling (Table 6). Fewer burn modifications are noted for deer in the MLT, and more carnivore gnawing and cut marks are noted for elk in the MLT. Among ruminants more generally, incidences of burning, cut marks, and fractures to fresh bone increase in the MLT, while insignificant changes in carnivore modifications and percussive impact marks were noted. The count of medium to large mammal diaphysis specimens with fractures to fresh bone also increase from the Middle (n=106) to MLT (n=146)

**Table 6**  
**PROPORTIONS OF MODIFIED RUMINANT ELEMENTS**  
**(%NISP) BY PERIOD**

Taxon	Modification	Middle Period	MLT Period	Z-test results
Deer	%Burned	59.6	38.3	$Z=3.4512, p<0.01$
	%Carnivore gnawing	9.9	10.6	$Z=-0.1875, p=0.85$
	%Cut marks	26.8	29.8	$Z=-0.5463, p=0.58$
	%Fractured on fresh bone	20.7	31.9	$Z=-2.1256, p<0.05$
	%Percussive impact marks	3.3	5.3	$Z=-0.847, p=0.40$
Elk	%Burned	34.7	34.7	$Z=0.0087, p=0.99$
	%Carnivore gnawing	16.2	28.0	$Z=-2.2327, p<0.05$
	%Cut marks	35.6	58.7	$Z=-3.4847, p<0.01$
	%Fractured on fresh bone	14.8	22.7	$Z=-1.5656, p=0.12$
	%Percussive impact marks		2.7	$Z=0.4248, p=0.67$
All ruminants	%Burned	46.7	32.5	$Z=4.3451, p<0.01$
	%Carnivore gnawing	8.6	10.7	$Z=-1.0937, p=0.28$
	%Cut marks	23.2	34.2	$Z=-3.7535, p<0.01$
	%Fractured on fresh bone	21.0	32.2	$Z=-3.9272, p<0.01$
	%Percussive impact marks	3.3	4.1	$Z=-0.6452, p=0.52$

components ( $Z=-7.8051, p<0.01$ ), perhaps reflecting intensified marrow processing. Percussive impact marks show no statistically significant trend over time for ruminant specimens, but low proportions of specimens with percussive impact marks are expected for long bones broken by anvil and hammerstone. These low proportions of impact marks for diaphysis fragments are also expected in contexts in which grease processing behaviors may have overwritten marrow processing marks.

## DISCUSSION

Specimen size and fragmentation trends, analyzed with respect to rates of percussion impact marks and evidence of fractures on fresh bone, have the potential to reveal palimpsests of carcass processing decisions that were not visible by element abundances alone. Positive correlations between element abundances and utility do not clearly indicate the processing of these products—only perhaps the selection for grease-rich and marrow-rich elements. The distinction between extent and intensity of fragmentation provides a way to distinguish between marrow extraction and grease processing in datasets such as this. Following Wolverton and colleagues (2008; see also Lyman 1994b; Nagaoka 2005, 2006;

Nagaoka et al. 2008; Wolverton 2002), indices used to infer these behaviors reveal increasing dependence on within-bone fats, and grease in particular, over time at this village site. The analysis of taphonomic and metric indicators is paramount to interpretations of debris from these behaviors. Low rates of element completeness, percussive impacts, and fractures to fresh bone indicate that marrow was extracted from ruminant long bones, and intense fragmentation and small specimen sizes generally match expectations for the extraction of grease. Further, the consistency in size and fragmentation level across elements of the MLT assemblage indicate that all elements were heavily processed to the same extent, strongly suggesting reduction for grease extraction. It is likely that grease-rendering overprinted some evidence for marrow extraction, particularly in the MLT Period. The results do not clarify whether grease production or marrow extraction was the main selective force for ruminant processing, just that they were both utilized in ruminant carcass processing to some degree.

It is expected that marrow processing resulted in many diaphysis specimens and a high extent of fragmentation, fresh fractures, and percussive impacts. It is clear that when behaviors such as marrow processing increase long bone fragmentation, the result is initially high NISP values and high fragmentation indices. When grease rendering further breaks up these specimens (high fragmentation intensity), there is a point at which these behaviors start to reduce NISP and deflate the fragmentation index (Lyman 1994a; Nagaoka et al. 2008; Wolverton et al. 2008). Processing of within-bone fat is suggested by the deflated values that are reported for fragmentation indices despite the overall smaller fragments that comprise the MLT Period assemblage. Furthermore, density-mediated attrition matches the presence of some carnivore modifications and evidence for grease processing. Elements previously processed for marrow or grease extraction are less attractive to carnivores (Ugan 2005; Nagaoka 2014), yet both processes impact low-density elements most heavily.

Other case studies have suggested that intensified processing of within-bone fats was a common solution to climate-driven nutritional stress in various geographical and temporal contexts (Munro 2004; Outram 2001). Similarly, the components at CA-SCL-119 span the onset of the local expression of the Medieval Climatic

Anomaly (A.D. 950–1150). This climate change event was characterized by warm temperatures and extreme drought (Jackson and Ericson 1994; Jones et al. 1999; Malamud-Roam et al. 2006). The event impacted the San Francisco Bay (Malamud-Roam et al. 2006), Santa Barbara Channel (Jones et al. 1999; Kennett and Kennett 2004; Raab et al. 1995) and Sierra Nevada range (Graumlich 1993; Stine 1994), and likely also affected groups in the Santa Clara Valley. The climate change was likely stronger in this region than in the San Francisco Bay area, as the valley does not benefit from a major river system's runoff (Malamud-Roam et al. 2006). Responses to the environmental instability of the MLT may be reflected by material pattern shifts around A.D. 1000 that include the appearance of large numbers of arrow points, the disappearance of earlier styles of stemmed points, and changes in bead types (Jones et al. 2007:139). Shifts in material patterning may be related to reorganization of economic relationships and adaptive responses to simultaneously shifting resource availability. During the MLT the combination of changing environmental conditions and high population densities may have caused particularly stressful times. Thus, the component assemblages in this case study are appropriate for evaluating the presence of carcass processing strategies associated with risk-management during a period of expected climate change. Further, the craft and industrial uses of within-bone fats, such as for fuel and marrow for the tanning process (Outram 2001:401), along with the use of the bones themselves as tools, must be considered alongside nutritional analyses in order to understand carcass processing decisions concerning ruminants at CA-SCL-119.

### CONCLUSIONS

The approach advocated in this case study is one of fine-grained analytical methods used to identify nutritionally-based behaviors and other carcass processing decisions. Basic taphonomic and metric data allow one to infer carcass processing decisions that may otherwise go unnoticed in more standard utility analyses mobilizing optimal foraging perspectives of carcass exploitation. Furthermore, these data allow an analyst to critically consider how palimpsests of carcass processing behaviors may leave overprinting marks in the archaeofaunal

record. Application of the fine-grained approach to element representations at CA-SCL-119, when taken together with taphonomic and metric data, reveals changes in the manipulation of ruminant products over a period of expected climate change.

Any approach solely relying on element abundances and utility correlations is subject to equifinality of results, and an approach considering differential destruction of elements or taxa due to intensive carcass processing is recommended. The approach used in this study does not replace nutritional utility analysis but adds a taphonomically-derived nuance to it by taking into account multiple lines of bone surface and fracture modifications. The very nature of archaeofaunal assemblages, which are biased by many factors—e.g., human processing of food and non-food byproducts, carnivore scavenging and gnawing, trampling, excavation screen sizes and recovery methods—suggests that a silver bullet, such as utility curves, should never be accepted as a sole means of inferring human behavior from bones. The use of taphonomic and metric evidence allows for an interpretation of post-transport decisions essential to understanding human-animal relationships in the past as well as the nutritional and industrial needs met by carcass processing.

### ACKNOWLEDGEMENTS

Special thanks to Jacob Fisher, Jun Sunseri, Diane Gifford-Gonzalez, Steve Wolverton, and two anonymous reviewers for valuable comments on previous versions of this manuscript which greatly improved the paper, and to Blaine Cooper for assistance with the figures. Analysis of the CA-SCL-119 fauna was made possible by a grant from the National Science Foundation (Dissertation Improvement Grant BCS-0840356).

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