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TAKING THE MEASURE OF A MARK:
EXPLORATORY SIZE AND SHAPE ANALYSIS OF CUT MARKS

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ABSTRACT—A database of 128 measured incised butchery marks (i.e., the classic cut mark) was the basis for exploratory statistical tests of length and width measurements from late Pleistocene mammoth localities and an early Holocene bison locality. The tests reveal several trends. The initial approach uses univariate descriptive statistics, regression, and ANOVA to examine differences in size and shape of marks. Significant differences are noted in length and width of marks based on location, element, and type. Length and width variables demonstrate low variability within incised marks. Results demonstrate a consistency in incised marks across the two taxa. Other consistencies are noted that indicate a regular or standardized way of producing marks in particular places on bones and on particular elements. Location or placement of marks appears to influence mark length, and in general, mark width is constrained. Mark orientation can at times influence mark length. Shape of mark ends may be related to the type of tool and size of tool bit. Using a morphometric approach (size and shape) removes some of the subjectivity in evaluating marks on a visual basis. While exploratory in nature, this morphometric approach crosscuts time and space boundaries and should be applicable to any bone assemblage.

Key Words: cut marks, morphometrics, mammoth, bison, butchery, taphonomy

INTRODUCTION

Issues of evidence recognition, human intervention in bone beds, and subsistence strategies are being investigated in various areas of the late Pleistocene North American grasslands (Fig. 1). Such studies incorporate different landscape settings, climate, and environments.

The protocol being used to examine bone from early sites has a focus on methodology that is based on taphonomy, biotechnology, and morphometrics (size and shape). The focus is on marks made on bone by people (hereafter referred to as cultural marks), and particularly those made during carcass processing. Research has been undertaken to explore mark parameters, potential patterns and consistencies, and interpretive value.

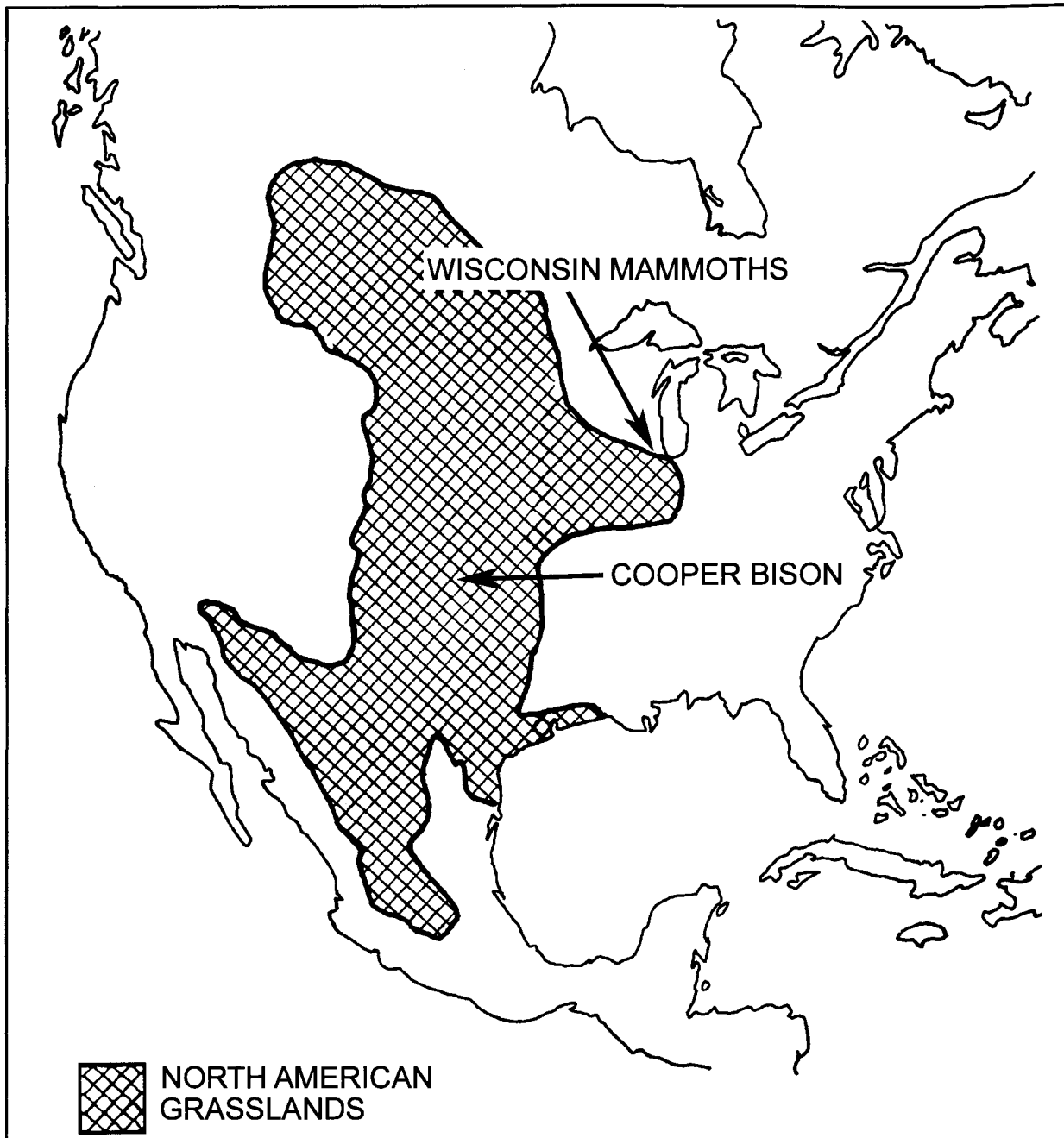Following the seminal work of Shipman (1981a, 1983,

Figure 1. Map of North American Pleistocene grasslands showing the location of the Wisconsin localities and the Cooper site.

1988, 1989), cultural marks made on bone are distinguished from natural agencies and are described using both qualitative and quantitative means (Johnson 2005, 2006, 2007a, 2007b; Johnson and Bement 2009). Qualitative means involve identifying features that characterize cultural marks, provide a basis for the range of variation of such marks, and enhance the classic definition of a cut mark (Shipman 1981b; Shipman and Rose 1983, 1984).

Quantitative means involve length and width measurements and other aspects of the size and shape of cultural marks and the number of actions that went into creating the mark.

The current analysis is exploratory in nature, and involves statistical examination and comparison of marks between two taxa. Although a variety of cultural marks occur (e.g., percussion [Johnson, 1985; Blumenschine and
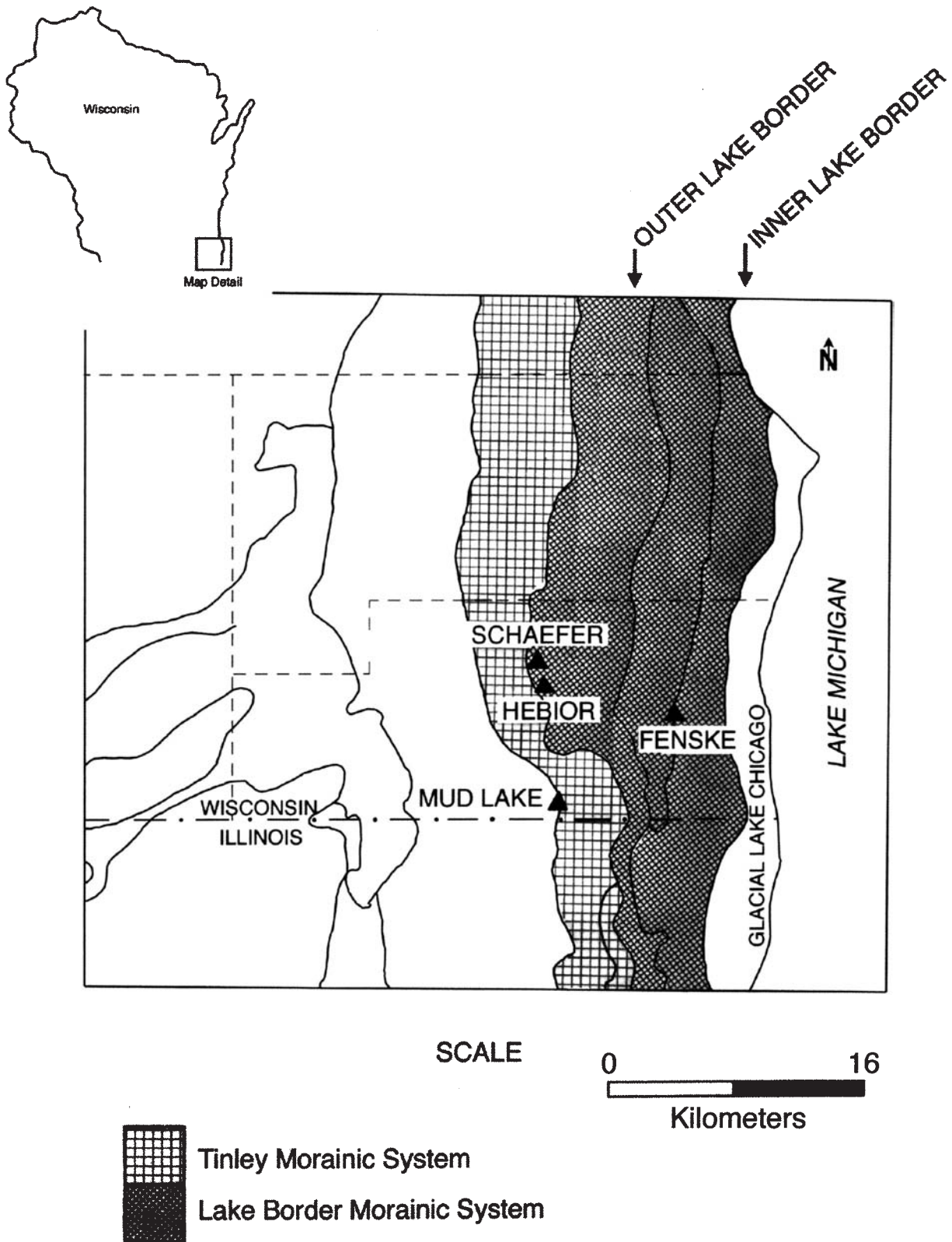
Figure 2. Map showing the relationship of the localities in southeastern Wisconsin.

Selvaggio 1988; Pickering and Egeland 2006]), the focus for this exploratory analysis is on cut marks, and in particular, marks made during the butchery process by flaked lithic tools. Specifically, the type of mark examined is that of an incised mark (the classic cut mark [Shipman 1981a; Shipman and Rose 1983; see also Potts and Shipman 1981; Lyman 1994; Fisher 1995; Blumenschine et al. 1996]) produced as the result of a sharp-edged object slicing into the bone). These marks are noted as mark type 1 in Johnson's (2007b) categorization scheme.

Previously determined cut marks on different large species (Johnson 2007b; Johnson and Bement 2009) were used for comparative purposes in order to provide an initial range of interspecies variation and explore generalizations across species. The purpose was not to assess whether the marks on the Wisconsin mammoth were the result of human agency (i.e., cultural marks). From the authors' perspective, that determination had been made (Johnson 2006, 2007b) and the intent was not to repeat that analysis here. The purpose was to advance a method using morphometrics that would remove some of the subjectivity in evaluating marks on a visual basis and specifically for the type of cultural mark being examined.

The analysis, while using statistical tests, was exploratory, with the objective being to probe the data for patterns and trends using the available information. These initial findings, then, could form the basis for further examination of interspecies incised marks using an increased sample size and additional species. The intent, then, was not to examine behaviors involved with carcass acquisition, processing, or consumption based solely on the initial findings. Exploration was driven by five assumptions: (1) that the cut marks were related to the butchering process in which flaked lithic tools were used; (2) that the cut marks would exhibit consistent characteristics; (3) that length and width provide the simplest approach to a standardized description of the general morphology; (4) that cut marks would share the same characteristics regardless of taxon, with the constants being bone material and use of flaked lithic tools in butchering; and (5) that exploratory analysis would detect behavioral information and provide a direction for future research. The hypothesis, then, is that the morphology of incised marks across species would be the same.

Data from two distant locations on the North American grasslands involving two taxa have been used in the exploratory analysis (Fig. 1). The standard used for dates is that of radiocarbon years before present, that is, dates have not been calibrated to calendar years. A cluster of four mammoth localities in close proximity to each other in southeastern Wisconsin represents the northernmost
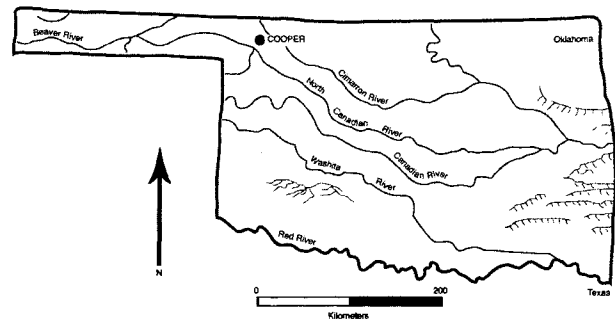

Figure 3. Map showing the Cooper site in western Oklahoma.

location (Figs. 1, 2). We know that these sites involve early peoples, based on cultural marks on bones (Johnson 2007b; Johnson et al. 2007) and lithic artifacts found at two of the localities (Overstreet 1993, 1996, 1998; Overstreet et al. 1993, 1995). Radiocarbon dates provide a time period of ~13,530 to 11,200 years before present (Dallman et al. 1996; Overstreet and Stafford 1997; Overstreet 1998; Overstreet and Kolb 2003; Joyce 2005). The Cooper site (Bement 1999), along the northern bluff of the Beaver River in northwestern Oklahoma, represents the southernmost location (Figs. 1, 3). Cooper is an arroyo-trap bison kill site recording three episodes within the Folsom period. Both Folsom points and lithic tools are in association with the kills. Radiocarbon dates provide a time period of ~10,600 to 10,500 years before present, indicating a 100-year time span for the kills (Johnson and Bement 2009).

Examining marks on bones and what constitutes butchery marks (e.g., Blumenschine and Selvaggio 1988; Olsen and Shipman 1988; Fiorillo 1989; Calpaldo and Blumenschine 1994; Blumenschine et al. 1996; Domínguez-Rodrigo and Piqueras 2003; Johnson 2006; Domínguez-Rodrigo et al. 2009; Galán et al. 2009) speaks to regional, national, and global issues. Regionally, demonstrating cultural marks and examining butchering patterns are significant in Paleoindian studies of resource utilization, subsistence, and landscape use (Hofman et al. 1989; Tankersley and Isaac 1990; Bement and Buehler 1997). Nationally, three of the mammoth localities date earlier than Clovis and would indicate people and the use of mammoth prior to that time, and therefore are significant in terms of the timing of human entry into the Americas (Dillehay and Meltzer 1991; Grayson 1998; Dillehay 2000; Haynes 2002; Meltzer 2009; Pitblado, 2011).

On a global basis, another consideration is the type of evidence accepted as demonstrating the early presence of people. The cut marks on the Wisconsin mammoth have been questioned as natural or modern modifications,

primarily due to the age of the sites and general lack of lithics (Cannon and Meltzer 2004; Krasinski and Haynes 2008; but see Collins et al. 2008). Age should not be a factor in deciding whether marks are cultural or natural (e.g., recent controversy in Ethiopia [Domínguez-Rodrigo et al. 2010, 2012]; McPherron et al. 2010). Nor should the absence or minimal presence of lithics be factors. Cut marks are a direct link to people, as people had to make the marks regardless of whether the implements used to make the marks were left behind with the bone refuse. Examining marks in more detail should provide the basis for a more rigorous protocol and stronger definition of cultural marks that could be applied across time lines and prey species to aid in identifying the early presence of hominids and examine their subsistence patterns. Researchers are beginning to examine cut marks more closely, to debate what constitutes a cut mark, and to call for more standardized terminology (e.g., Domínguez-Rodrigo et al. 2009; de Juana et al. 2010; James and Thompson 2012; McCarthy 2012; Merritt 2011, 2012; Otárola-Castillo et al. 2012; Welch et al. 2012). This study reflects that trend.

SITES

Wisconsin Mammoth

The mammoth localities (Figs. 1, 2) are Fenske (47KN240), Mud Lake (47KN246), Schaefer (47KN252), and Hebior (47KN265). Each represents a single disarticulated carcass ranging in completeness from one element to ca. 90% (Overstreet 1998; Johnson 2006). These localities are within a glacial landscape that was formed through the wasting ice of the Lake Michigan lobe or water plane fluctuations of glacial Lake Chicago (Hansel 1983; Schneider 1983; Hansel et al. 1985). They lie within lowlands between moraine ridges (Schneider 1983; Overstreet 1998).

The localities were discovered accidentally through water diversion projects from the 1920s to 1960s. Subsequent fieldwork in the 1990s confirmed the stratigraphic context of the remains at each locality (Overstreet 1996) and recovered the undisturbed portions of the Schaefer and Hebior mammoth carcasses (two localities with associated lithics) through excavations that also detailed the stratigraphy and paleovegetation (Huber and Overstreet 1990a, 1990b; Huber and Rapp 1992; Overstreet et al. 1993; Fredlund et al. 1996; Overstreet 1996, 1998; Overstreet and Kolb 2003). Bones of the Schaefer and Hebior mammoths were located well below intact peat layers and unaffected by modern agricultural plowing. Given the

similar stratigraphy, remains from the other two localities most likely also lay well below any impact from modern plowing activities.

Summarized by Overstreet and Kolb (2003:94) and Joyce (2005:76, 2006:53), 25 purified bone collagen dates are published for the four localities and 16 wood dates for Schaefer. Fenske is dated ~11,240–11,220 years before present. Mud Lake dates range from ~13,530 to 13,440 years before present, while dates for Hebior range from ~12,590 to 12,480 years before present. The Schaefer bone collagen ages date the locality between ~12,900 and 12,570 years before present. Wood associated with the Schaefer mammoth comes from underneath, within, and on top of the bone concentration. The wood dates provide a range of ~12,940–11,980 years before present.

A detailed taphonomic analysis indicated that both natural and cultural processes had influenced the bone beds (Johnson 2006). Rodent gnawing was absent and carnivore activity was limited, with tooth punctures being the most common damage. The frequency of trample marks was low. Bone axis orientation data, examined statistically through two different approaches, indicated no significant departure from a random distribution of bone. Water transport was not a factor in bone bed formation nor was water movement within the bone piles a disturbance factor. Neither beaver gnawing nor ice rafting were the cause of the bone damage, nor could carnivore activity or trampling account for creation of all the marks.

Approximately 7.6% of the combined assemblage, affecting 30 bones from the four carcasses, exhibits evidence of cultural modification. A total 200 marks on bones from the localities are identified as cultural, 84 of which are incised marks (i.e., the classic cut mark; Johnson's [2007b] mark type 1). These marks occur primarily on appendicular elements, as demonstrated by a chi-squared goodness-of-fit test (Johnson 2007b). The other 116 marks are pry marks (created as a result of a pointed to rounded object being moved along the bone surface primarily at joints; Johnson 2007b).

Cooper Bison

The Cooper site (34HP45; Bement 1999) is located on the Southern Plains (Figs. 1, 3) along the Beaver River (or North Canadian) in the western Sand Dune Belts. This area as a whole is grassland with riparian deciduous wooded valleys today, and was grassland during Cooper occupation (Bement et al. 2007).

Three episodes of bison trapping took place in the arroyo over a very short time span within the Folsom period

(Bement 1997:95, 1999:172). Radiocarbon ages on petrosals from skulls in each of the kills provided sequential dates of ~10,600 years before present (lower kill), ~10,530 years before present (middle kill), and ~10,505 years before present (upper kill) (Johnson and Bement 2009). Each episode was a kill of a cow-calf herd during late summer—early fall (based on age, sex, and seasonality data). Kill size varied from a minimum 20 bison in the lower kill to 29 in the other kills (Bement 1997, 1999). As up to 50% of each kill had been removed through bluff erosion (Bement 1999:52), each episode potentially contained twice that number of bison. The Cooper site, both in terms of individual episodes and as an aggregate, represented large-scale kills.

Bison for all three episodes primarily were intact carcasses, with incomplete carcasses or disarticulated remains primarily at the eroded edge of the site. Taphonomic analysis indicated that both natural and cultural processes had influenced the bone beds (Bement 1999). Gourmet butchering was the focus of cultural activity, involving only meat-stripping of the carcasses (Bement 1999:138).

Based on an independent assessment of the bison bones, ca. 2.5% of the assemblage, affecting 99 elements from 36 carcasses, exhibited evidence of cultural modification (Johnson and Bement 2009). Of the carcasses, 96 bones came from 34 excavated carcasses; three were from slump deposits. This rate indicated that ca. 42% of recovered carcasses reflected cultural damage. The number of carcasses that had elements exhibiting cultural modification varied by kill, with decreasing frequency from upper to lower kills. That pattern was attributed at least partially to worsening bone preservation with depth. A total 149 marks on bones from the three kill episodes were identified as cultural, 45 of which are incised marks (i.e., the classic cut mark; Johnson's [2007b] mark type 1). These marks occurred exclusively on vertebrae and ribs (Johnson and Bement 2009). While the lower kill exhibited other types of cultural modifications to the bones, the incised marks came from the upper and middle kills. The rest of the marks consisted of percussion blow marks made by a hammerstone and indentations made by a bone butchering tool (Johnson and Bement 2009).

METHODOLOGY

The raw cultural mark data and procedure used to determine cultural and natural agencies are in Johnson (2006, 2007b) for the Wisconsin localities and in Johnson and Bement (2009) for Cooper. Images of cut marks from the Wisconsin localities and Cooper provided here (Fig. 4) are for reference purposes, and additional images are in Johnson (2007b), Johnson et al. (2007), and Johnson and Bement (2009). Potential cultural marks have not been subjected to multivariate analysis (e.g., Domínguez-Rodrigo et al. 2009, 2012) to verify segregation of cultural from trampling marks. Nevertheless, the procedure followed has eliminated the noncultural modifications and has produced a final subset of elements that exhibited cultural modification. A total 129 cut marks (i.e., incised marks; mark type 1) are within that final subset (Wisconsin = 84 cut marks; Cooper = 45 cut marks).

All marks were observed visually using a binocular microscope up to 63× magnification. Equipment and software to produce three-dimensional images and measurements (Bello and Soligo 2008; Bello et al. 2009) were not available at the time of this study. Nevertheless, molds were taken, replicas were made and coated following the protocol developed by Shipman (1981a, 1988, 1989, 1997; Shipman and Rose 1983), and the replicas were scanned using a Hitachi S-570 scanning electron microscope. These scans and images provided supplemental information to the observed data.

Variables (set forth in Johnson 2000, 2007b) used in the exploratory analysis were mark length, width, location, orientation, and morphology. Length and width measurements were recorded to the nearest 0.1 mm using a digital caliper; depth could not be taken reliably. Location referred to the placement of the mark on the element. Bone line drawings were used to record the mark placement. Placements were grouped and categorized to general location such as distal or proximal end, diaphysis, articular surface, or facet. Mark orientation to the long axis of a bone was categorized as right diagonal, left diagonal, perpendicular, parallel, or subparallel.

Morphology included shape of trough, shape of adjacent walls, number of strokes, and shape of stroke end. Trough shape was characterized as V-shaped or U-shaped. The angle between the arms of the V varied from tightly narrow through broad (as noted by other authors, e.g., Bello and Soligo 2008; de Juana et al. 2010). Wall configuration was categorized as at different heights and angles or at the same height and angle. With the first configuration, one wall is a steep-sided, taller wall and the other a shallow-sided, shorter wall (also noted by Bello and Soligo 2008). The number of strokes was a count of the number of actions (impacts or hits) that contributed to the creation of the mark. The number was recorded and categorized as simple (1 stroke) or complex (more than 1 stroke). Each mark had two ends (termini), that is, one at either end of the stroke. Eight descriptors characterized a

mark's end: blunted, tapered, flared, flat-pointed, lazy-V, feathered, obliterated, eroded).

For statistical analysis, length and width measurements were treated as continuous data. Small samples can be problematic, so two approaches were taken to minimize the effect. Groups with small sample sizes either were eliminated from a particular analysis or were combined with similar data types (e.g., all vertebrae types grouped together).

The initial approach used univariate descriptive statistics and regression and one-way analysis of variance (ANOVA) to test for significant differences in size and shape of marks (Sokal and Rohlf 2011). On occasion, an analysis of covariance (ANCOVA) was used. A confidence level of 0.05 was set for all statistical tests unless otherwise noted.

One-way ANOVA evaluates whether two or more sample means differ more than would be expected by chance. The one-way ANOVA is more general than regression analysis, as it can be used for identifying relationships between criterion variables (length and width) and predictor variables (the groups, e.g., element, terminus, trough), whether or not the predictor variables are quantitative or qualitative. ANOVA tests for variation within the group as a whole, the results of which indicate whether the groups vary by the variable or not. ANCOVA is a more accurate method for testing significance between large numbers of populations (Sokal and Rohlf 2011). The main significance test in ANCOVA is the homogeneity of the Y-intercept for all groups. Testing the parallelism of slopes for length and width for all groups eliminates the dependence of one variable, and allows the data to be tested in its relationship of two variables (Sokol and Rohlf 2011). The observations are grouped according to a single criterion that in this analysis is mark type. All tests have been run with Minitab 11.2 software.

This set of statistical tests is exploratory. Others have applied statistical tests to examine cut marks. Domínguez-Rodrigo et al. (2009, 2012), for example, have used multivariate analysis (analysis of variance, principle component analysis, and logistic regression analysis) to determine differences between trampling and butchery cut marks. De Juana et al. (2010) also has used multivariate analysis (principle component analysis, ANOVA, and discriminant analysis) to differentiate cut marks made by retouched flakes from those made by handaxes. Capaldo (1995) has examined frequencies and binning data through nonparametric means that are suitable for qualitative data (Sokal and Rohlf 2011). What is being examined here is quantitative data, namely length and width,

and how those vary according to different variables. Quantitative data almost always are normally distributed, and parametric tests are by far the best approach to use for these data (Sokal and Rohlf 2011).

The results of an ANOVA did not indicate the group or groups responsible for the significant variation found. Therefore, pairwise tests were used whereby each group was tested against all other groups to determine the group(s) responsible for significant results in the ANOVAs. These pairwise tests were run to explore the dataset, rather than answer specific hypotheses about the dataset, because of the absence of a priori expectations. Alpha values were adjusted for pairwise tests in accordance with the Bonferroni correction to minimize the chance of recording a false positive (Sokal and Rolf 2011). T-tests subsequently were performed to examine specific questions as appropriate.

RESULTS AND COMMENTS

Although the Wisconsin mammoth and Cooper bison datasets consist of more than one mark type, they both have what was identified as mark type 1 (i.e., an incised mark; Fig. 4) with the Wisconsin mammoths. Overall, the damage morphology associated with this type of mark is a clean, precise incision or slice into the cortical surface. Comparison between the two datasets, then, is made only with incised marks (type 1). Other mark types are taxon-specific and include the pry marks on mammoth articular surfaces and percussive marks on bison vertebrae made by bone butchering tools (Johnson 1985, 2007; Johnson and Bement 2009). Results of the ANOVA and ANCOVA runs are presented in Table 1, with significant results bolded.

Wisconsin Dataset

Length. An ANOVA of the Wisconsin length variables found that length for incised marks was significantly different among the four groups. Post hoc Fisher's pairwise tests (alpha adjusted to 0.006) indicated that the significant difference is driven by the shorter marks from Mud Lake and Schaefer, both significantly shorter than marks from Fenske and Heibor (Fenske mean length = 16.0 mm; Heibor mean length = 15.4 mm; Mud Lake mean length = 9.5 mm; Schaefer mean length = 10.5 mm). Mud Lake and Schaefer incised marks exhibited similar mean length values, while those from Fenske and Hebior are similar to each other.
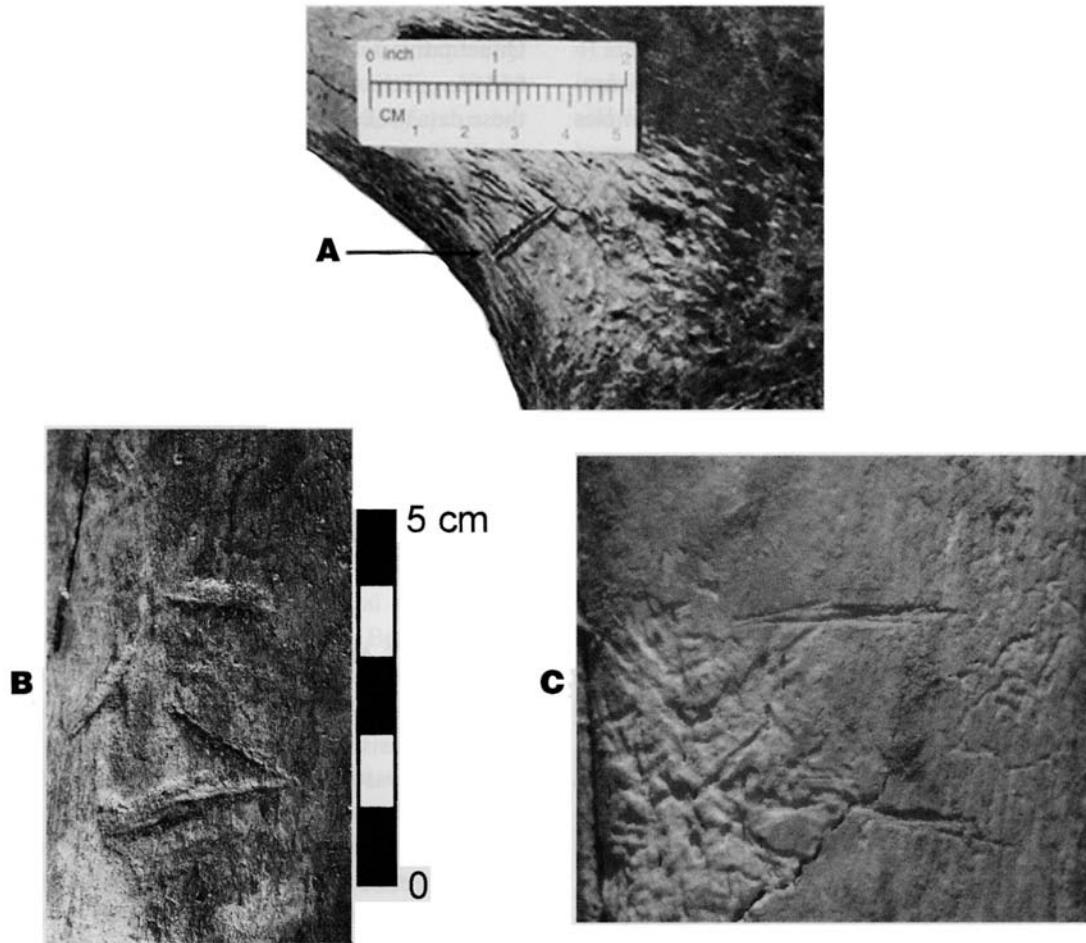
Figure 4. Mark types in the Wisconsin and Cooper datasets. A. Mark type 1 (narrow version), Wisconsin mammoths. B. Mark type 1 (wide version), Wisconsin mammoths. C. Mark type 1, Cooper bison.

Width. When width is tested with ANOVA for incised marks, the results are not significant. Heibor and Schaefer, however, demonstrate narrower incised marks than Fenske and Mud Lake (Fenske mean width = 2.2 mm; Mud Lake mean width = 2.1 mm; Heibor mean width = 1.29 mm; Schaefer mean width = 1.4 mm). Post hoc Fisher's pairwise tests (alpha adjusted to 0.006) also found an insignificant difference between the localities. While Heibor and Schaefer incised marks are ca. 40% narrower than Fenske and Mud Lake incised marks, differences in the number of samples (Fenske = 14; Mud Lake = 44; Heibor = 5; Schaefer = 9) between the localities negatively impact the statistical tests.

Length and Width. Linear regression found no correlation between length and width (r^2 = 0.03). ANCOVA likewise was insignificant, suggesting no differences in the relationship between length and width of incised marks among the four Wisconsin localities.

Cooper Dataset

Length and Width. Using ANOVA, no significant difference was found in mark length or width between the upper and middle kills of the Cooper incised marks. The length to width relationships of incised marks between the upper and middle kills also were consistent, with ANCOVA finding no significant difference and linear regression with no correlation (r^2 = 0.001). Mark size was consistent between the kills, and all marks are short and narrow.

Combined Wisconsin and Cooper Datasets

Length. An ANOVA testing length grouped by locality (i.e., Wisconsin localities and Cooper) found that the groups differed significantly. Post hoc Fisher's pairwise tests (alpha adjusted to 0.005) found that Cooper marks are not significantly different in length from Mud Lake

TABLE 1.
RESULTS OF STATISTICAL TESTS ON THE WISCONSIN MAMMOTH AND COOPER BISON DATASETS

Locality	Category	Test	Results*
Wisconsin	Length	ANOVA	$F = 7.16$; $df = 3$; $p = <0.01$
	Width	ANOVA	$F = 1.01$; $df=3$; $p = 0.39$
	Length and width	ANCOVA	$F = 1.41$; $df = 3$; $p = 0.74$
	Length and trough shape	ANOVA	$F = 0.492$; $df = 2$; $p = 0.689$
	Width and trough shape	ANOVA	$F = 31.60$; $df = 2$; $p = <0.001$
	Length and strokes	ANOVA	$F = 5.10$; $df = 1$; $p = 0.27$
	Width and strokes	ANOVA	$F = 2.67$; $df = 1$; $p = 0.11$
	Length and trough wall	ANOVA	$F = 0.04$; $df = 1$; $p = 0.85$
	Width and trough wall	ANOVA	$F = 0.03$; $df = 1$; $p = 0.87$
	Length and R mark end	ANOVA	$F = 2.41$; $df = 4$; $p = 0.05$
	Width and R mark end	ANOVA	$F = 2.07$; $df = 4$; $p = 0.09$
	Length and L mark end	ANOVA	$F = 2.12$; $df = 4$; $p = 0.08$
	Width and L mark end	ANOVA	$F = 1.57$; $df = 4$; $p = 0.19$
	Length and orientation	ANOVA	$F = 1.43$; $df = 3$; $p = 0.24$
	Width and orientation	ANOVA	$F = 0.95$; $df = 3$; $p = 0.42$
	Length and element	ANOVA	$F = 10.23$; $df = 5$; $p = <0.01$
	Width and element	ANOVA	$F = 5.36$; $df = 5$; $p = <0.01$
Cooper	Length	ANOVA	$F = 0.59$; $df = 1$; $p = 0.45$
	Width	ANOVA	$F = 2.68$; $df = 1$; $p = 0.11$
	Length and width	ANCOVA	$F = 0.06$; $df = 1$; $p = 0.81$
	Length and strokes	ANOVA	$F = 1.92$; $df = 2$; $p = 0.16$
	Width and strokes	ANOVA	$F = 2.05$; $df = 2$; $p = 0.14$
	Length and trough wall	ANOVA	$F = 2.86$; $df = 1$; $p = 0.10$
	Width and trough wall	ANOVA	$F = 1.27$; $df = 1$; $p = 0.27$
	Length and R mark end	ANOVA	$F = 1.76$; $df = 2$; $p = 0.019$
	Width and R mark end	ANOVA	$F = 0.92$; $df = 2$; $p = 0.41$
	Length and L mark end	ANOVA	$F = 4.17$; $df = 2$; $p = 0.02$
	Width and L mark end	ANOVA	$F = 1.25$; $df = 2$; $p = 0.30$
	Length and orientation	ANOVA	$F = 4.13$; $df = 2$; $p = 0.02$
	Width and orientation	ANOVA	$F = 0.75$; $df = 2$; $p = 0.48$
	Length and element	ANOVA	$F = 7.38$; $df = 1$; $p = 0.01$
Combined	Length	ANOVA	$F = 14.31$; $df = 4$; $p = <0.001$
	Width	ANOVA	$F = 11.57$; $df = 4$; $p = <0.001$
	Length and width	ANCOVA	$F = 2.32$; $df = 4$; $p = 0.058$
	Length and width	ANOVA	$F = 5.10$; $df = 4$; $p = <0.01$
	Length and trough shape	ANOVA	$F = 4.21$; $df = 2$; $p = 0.02$
	Width and trough shape	ANOVA	$F = 100.695$; $df = 2$; $p = <0.001$
	Length and strokes	ANOVA	$F = 0.87$; $df = 2$; $p = 0.92$
	Width and strokes	ANOVA	$F = 1.67$; $df = 2$; $p = 0.19$
	Length and trough wall	ANOVA	$F = 2.45$; $df = 1$; $p = 0.12$
	Width and trough wall	ANOVA	$F = 0.59$; $df = 1$; $p = 0.44$
	Length and R mark end	ANOVA	$F = 9.61$; $df = 6$; $p = <0.01$
	Width and R mark end	ANOVA	$F = 3.20$; $df = 6$; $p = <0.01$
	Length and L mark end	ANOVA	$F = 3.82$; $df = 6$; $p = <0.01$
	Width and L mark end	ANOVA	$F = 2.30$; $df = 6$; $p = 0.04$
	Length and orientation	ANOVA	$F = 2.88$; $df = 3$; $p = 0.04$
	Width and orientation	ANOVA	$F = 1.00$; $df = 3$; $p = 0.40$
	Length and orientation	ANOVA	$F = 11.45$; $df = 11$; $p = 0.01$

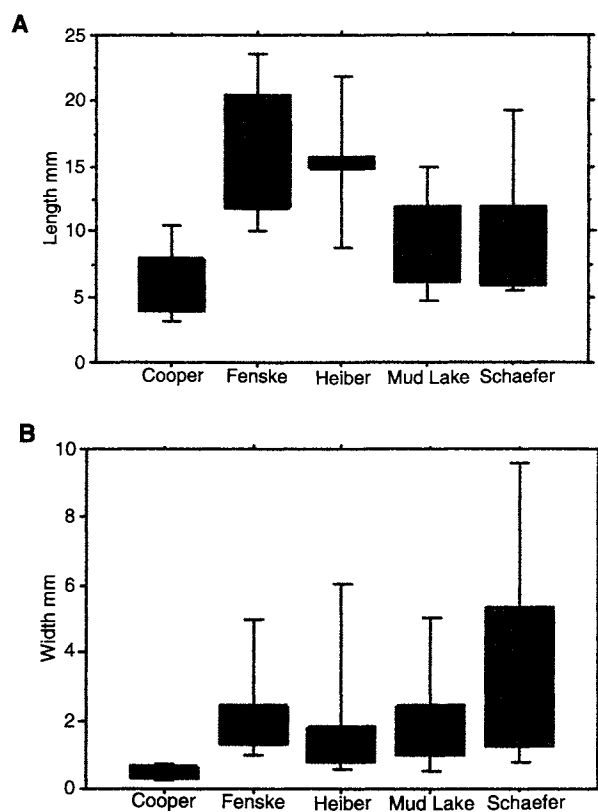*Results in bold are statistically significant.

A

B

Figure 5. Boxplots for (A) length and (B) width of mark type 1 grouped by locality for Wisconsin and Cooper marks.

and Schaefer marks, but they differ significantly from Hebior and Fenske marks (Fig. 5A). Incised marks, then, were not significantly different between the taxa.

Width. An ANOVA testing width grouped by locality found that the groups differed significantly. In post hoc pairwise Fisher's tests (alpha adjusted to 0.005), marks on Cooper bison were significantly narrower than marks from all of the Wisconsin localities (Fig. 5B).

Length and Width. An ANCOVA examining the length to width relationship (gross shape) of incised marks in the combined datasets found that the groups differed significantly. In post hoc pairwise Fisher's tests (alpha adjusted to 0.005), significant results were found in the incised mark length-to-width relationship between Cooper and Mud Lake and between Mud Lake and Schaefer. The pairwise tests did not find any significant difference between Cooper, Schaefer, and Heibor, meaning that incised mark length-to-width relationship was similar. With a very low alpha, any difference between these three sites would have to be extreme to get a significant result.

ANOVA found a similar significant result. Post hoc pairwise Fisher's tests (alpha adjusted to 0.005) again found that incised marks on Cooper bison remains were significantly different in their length to width relationship from those at all the Wisconsin localities. Cooper incised marks were shorter and narrower than the Wisconsin incised marks. Linear regression found little correlation between length and width of incised marks (r^2 = 0.05). In general, the width of the mark did not increase as the length of the mark increases. This result underscores both the consistency and constraints in the marks across the taxa.

Mark Consistency in the Combined Datasets

To explore mark consistency, we examined the relationship between mark length and width and five nonmetric morphological characters: trough shape, stroke number, trough wall, mark ends, and mark orientation. Using these datasets, we defined a narrow trough as 2.2 mm or less in width. The data did not show a natural break, so the average of the mean and median were used to arrive at this arbitrary number. In examining trough width, the majority of measurements were in a tight cluster where no natural break was detected. That tight cluster indicated a limited range of variation in the width of the marks. This limited range, then, indicated the marks are very consistent.

Length and Width versus Trough Shape. For the Wisconsin dataset, ANOVA found no significant difference in mark length and trough shape, but a significant difference was found for width. This result was driven primarily by the broad V-shaped marks that are more than twice as wide as all other trough types.

For the Cooper dataset, all marks are even more constrained, and they formed a subgroup within the narrow trough definition of 2.2 mm (Cooper maximum width at 1.2 mm; Fig. 5A). Width does not appear to correlate with length (r^2 = <0.01), as short marks can be wide, relatively speaking. All marks wider than 0.8 mm are from marks shorter than 10 mm.

For the combined incised mark dataset, a significant difference occurs in length. This result appears driven primarily by Wisconsin broad V-shaped marks, which tend to be longer than the V- and narrow V-shaped marks (Fig. 6A). When width is tested, again a significant difference is found. Broad V-shaped marks are more than twice as wide as V- and narrow V-shaped marks (Fig. 6B).

Length and Width versus Number of Strokes. For the Wisconsin dataset, ANOVAs on number of strokes versus length or width found no significant difference in length
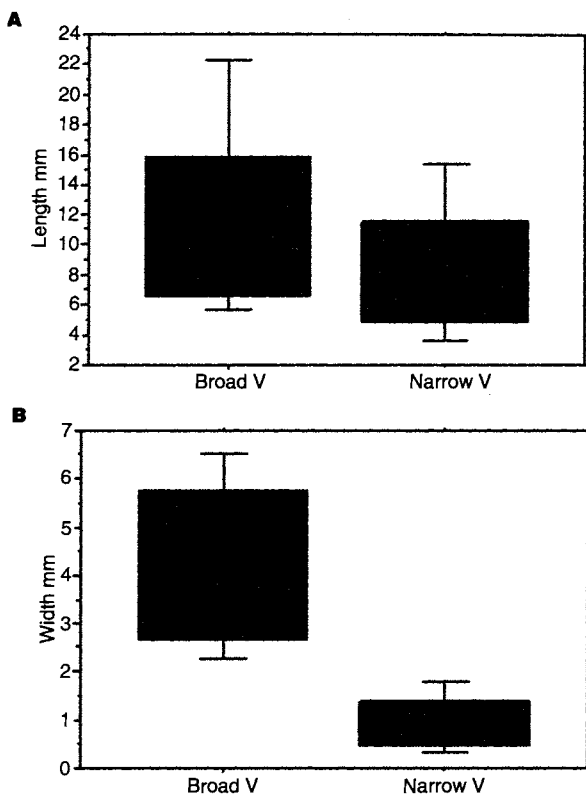
A

B

Figure 6. Boxplots for (A) length and (B) width of mark type 1 grouped by trough shape.

or width. The vast majority of marks (91%) had only one stroke. Marks having three or four strokes constituted one example each, and therefore were not used in the ANOVA. Two stroke examples occurred nine times (9%).

For the Cooper dataset, ANOVAs on number of strokes versus length or width also indicated no significant difference. Marks having four, five, or six strokes were represented by only one example each, and therefore were not appropriate for inclusion in the test. The mean values for both mark length and width, however, increased with the number of strokes. Marks having one, two, or three strokes accounted for 93.3% of the marks, while those marks having one or two strokes each accounted for 40% of the sample. Results from both the Wisconsin and Cooper datasets, then, indicate that the number of strokes did not dictate trough width.

For the combined datasets, an ANOVA found that neither length nor width grouped by stroke number differed significantly. The number of strokes, then, did not influence length or width.

Length and Width versus Trough Wall. For incised marks, trough walls are at different heights and angles. The steep-sided wall can be either the upper or lower wall.

For the Wisconsin dataset, although a lower steep-sided wall occurs slightly more frequently, no significant difference exists between upper and lower steep-sided walls in terms of length or width of an incised mark.

For the Cooper dataset, upper steep-sided walls occur with twice the frequency (66.7%) of lower steep-sided walls. Yet the result is the same as in the Wisconsin dataset, with no significant difference between upper and lower steep-sided walls in terms of length or width of an incised mark. Those with lower steep-sided walls, however, tend to be narrower and longer. Basically, which wall is steep-sided is not related to length or width of a mark. The relationship, however, is the position of the tool bit in a person's hand (Johnson 2007b). Bello and Soligo (2008:1549) confirm this relationship and note that tools held at acute or intermediate angles relative to the surface of the bone generally create a steep-sided—shallow-sided wall configuration. Those held perpendicular produce the same height configuration.

For the combined datasets, an ANOVA using length or width grouped by steep wall found that the two groups (upper or lower wall) did not vary significantly. These results suggest that length and width do not vary based on which wall is the steep-sided wall, even though the upper wall as the steep-sided one is more frequent (57%).

Length and Width versus Mark Ends. When we examined the datasets for a relationship between the ends of a mark (termini) and the size of the mark, we found variable results. For the Wisconsin dataset (Fig. 7A), the right terminus varies significantly by length but not by width. Shape and length of this end of a mark are related. The left terminus does not vary significantly by width or by length. Tapered ends, however, are associated with the shortest marks for both ends, and also with the narrowest for both mark end types.

For the Cooper dataset (Fig. 7B, 7C), neither length nor width varies significantly by right terminus, with pointed ends the shortest and narrowest. For the left terminus, length varies significantly. Results from pairwise Fisher's tests suggest that the left terminus significant result is driven by a difference between blunted and pointed shapes, in that marks with blunted ends are much shorter than pointed ends. Width is not significantly different for the left terminus shapes, although marks with a pointed left terminus again are the narrowest marks.

For the combined datasets, length is significantly different for right terminus shapes. Pairwise Fisher's tests indicate that the results are driven by marks with blunt, feathered, pointed, and flared shapes being shorter than
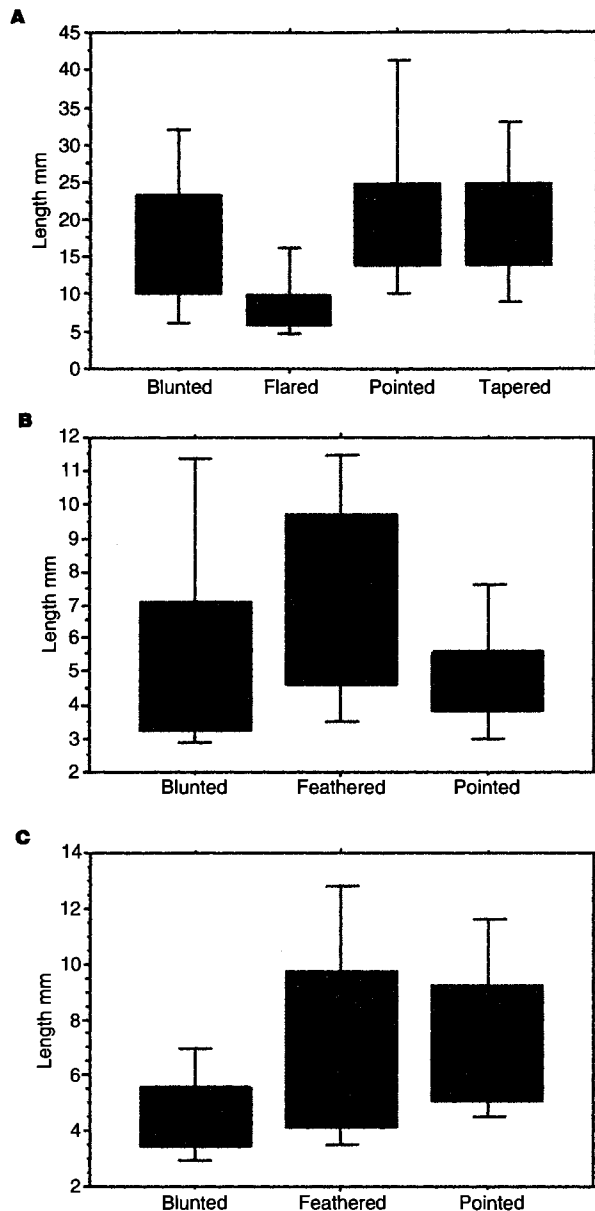
A

B

C

Figure 7. Boxplots for length of mark type 1 grouped by terminus. A. Right terminus for Wisconsin marks. B. Right terminus for Cooper marks. C. Left terminus for Cooper marks.

marks with the other shapes. Width also varies significantly for right terminus shape. Pairwise Fisher's tests indicate that the results are driven by marks with feathered, pointed, and eroded shapes being narrower than marks with other shapes.

The results for length grouped by left terminus shape are significant. Pairwise Fisher's tests indicate that the results are driven by marks with blunt, feathered, and flared shapes being shorter than marks with the other shapes. Width also varies significantly for the left terminus. Pair-

wise Fisher's tests indicate that the results are driven by marks with feathered, pointed, and tapered shapes being narrower than marks with the other shapes. Incised marks having a feathered left terminus are the shortest and narrowest of the incised marks across taxa.

Mark length and width appear to have some influence in the shape of the ends of incised marks. While entry or exit end may be a factor in the shape of mark ends, at this point neither can be determined by shape and width for incised marks. The type of tool and size of tool bit also may influence the shape and size of mark ends.

Length and Width by Orientation. For the Wisconsin dataset, ANOVA found that orientation does not vary significantly by length or by width. For the Cooper dataset, orientation varied significantly by length but not by width. Pairwise Fisher's tests indicated that right diagonal marks are the longer ones.

Using the combined datasets, length varies significantly but width does not. Pairwise Fisher's tests indicate that parallel and right diagonal marks are longer.

Mark Placement

For the Wisconsin dataset, incised marks were located more commonly along long bone diaphyses. An ANOVA of length by element found significant variation with the alpha adjusted to 0.007. A series of post hoc pairwise Fisher's tests found that incised marks on femora were longer than those on radii, ulnae, or ribs, and that marks on humerii also were longer than those on radii, ulnae, or ribs. An ANOVA of width by element likewise found significant variation with the alpha adjusted to 0.007. Post hoc pairwise Fisher's tests found that incised marks on femora were narrower than those on ribs, and that marks on metacarpals, radii, and ulnae are all narrower than those on ribs. In general, marks on ribs are twice as wide as those in all other categories examined. While length results may be an artifact of element size, all these elements present fairly sizeable surfaces relative to mark length. The result may be influenced by the location or placement of the mark. For example, marks on the radius and ulna frequently were along the narrow anterior muscle ridge.

For the Cooper dataset, incised marks occur only on ribs and vertebrae. An ANOVA testing mark length variation between ribs and vertebrae returns significant results. Marks on ribs are shorter. This result again may be an artifact of element size. Bison ribs present a much narrower surface than vertebral spines (spinous process).

For the combined dataset, ANOVA found a signifi-

TABLE 2.
FINDINGS FROM STATISTICAL ANALYSES OF MORPHOMETRICS OF INCISED MARKS
(CLASSIC CUT MARKS) ON WISCONSIN MAMMOTHS AND COOPER BISON REMAINS

Category	Wisconsin mammoth	Cooper bison	Across taxa
Length	Significantly different between two sets of localities	No significant difference between kills	No significant difference; consistent relationship
Width	Difference between narrower and broader incised marks	No significant difference between kills	Limited range of variation; marks on bison narrower than on mammoth
Length and width	Length-to-width relationship consistent	Length-to-width relationship consistent	Incised marks on bison shorter and narrower than on mammoth; length-to-width relationship consistent
Morphology:			
Trough shape	No significant difference for length; significant difference for length	No significant difference for length or width	Broad, long marks on mammoth significantly different than narrower, shorter marks on mammoth and bison
Stroke number	No significant difference for length or width	No significant difference for length or width	No significant difference; number of strokes did not influence length or width; consistent relationship
Trough wall	No significant difference for length or width	No significant difference for length or width	No significant difference; length and width do not vary based on wall height; consistent relationship
Mark ends	Right end varies significantly by length but not width; tapered ends associated with shortest and narrowest marks	Left end varies significantly for length but not width; pointed ends associated with narrowest marks	Both ends vary significant by length and width; feathered ends shortest and narrowest; length and width has some influence on shape of incised mark ends; consistent relationship
Orientation	No significant difference for length or width	significance difference by length but not width	Significant difference by length; orientation influenced length; no significant difference by width; consistent relationship
Location	Significant difference in length and width	Significant difference in length but not width	Significant difference in length; length varied on ribs and upper and lower limbs; consistent relationship

cant difference in length of marks. A series of post hoc pairwise Fisher's tests found that marks on upper limbs tended to differ significantly from those on lower limbs and ribs.

DISCUSSION

To reiterate, the statistical tests were chosen to explore the data for patterns and trends rather than answer specific hypotheses about the data. To determine the validity of patterns and trends found in this exploratory analysis, we would need similar data collected from the same taxa. Additional taxa would add to a more robust analysis. Nevertheless, to summarize the current findings, the marks have a consistency in mark production across taxa and a consistency in mark size (Table 2). These consistencies, as well as the overall pattern and internal complexity, indicate that the marks were not random occurrences.

Incised marks (mark type 1) are interpreted as the classic cut mark. This type occurs on a highly select group of

elements, although not the same groups between the Wisconsin mammoth and Cooper bison datasets. Statistical tests have explored three main areas. First, tests of length versus width indicate the incised marks are in two main groupings of shorter and longer marks. While these marks on the Wisconsin mammoth could be either narrower or broader, those on the Cooper bison always are narrow and more constrained in width than those on the Wisconsin mammoths. Nevertheless, results indicate that the length to width relationship is similar for Cooper, Schaefer, and Heibor and significantly different from that of Mud Lake and Fenske. These results mirror the interpretations that Cooper, Schaefer, and Heibor carcasses were fresh when butchered while those from Mud Lake and Fenske were stiffened (Johnson 2007b; Johnson and Bement 2009).

Our exploration of the internal relationships of the morphological characters of the marks in the combined datasets reveals that neither length nor width varied significantly. The number of strokes per mark versus length or width was inconclusive, as the vast majority of marks had only one stroke. No significant difference was found in terms of length or width for which wall was the steepsided one in incised marks. Variation by terminus was inconsistent. For the Wisconsin mammoth dataset, the right end of the mark varied significantly by width but not length while the left end showed no significant difference. For the Cooper bison dataset, the left end varied significantly by length while neither end varied significantly by width. Shape of the end varied significantly by length, with pointed ends being longer for the Wisconsin mammoth dataset and feathered ends for the Cooper bison dataset. Feathered ends were the result of a mark being composed of more than one stroke. While the number of strokes within a mark appears not to influence width, that number can affect the length of the mark.

In terms of external relationships for the marks, mark orientation varied highly significantly by length but not by width. Although the dominant orientation was not consistent across the databases, nevertheless, mark orientation influenced mark length across taxa. If orientation is related to hand and tool position, the addition of orientations other than the dominant one on the same element would indicate a range of hand or tool motion being used to accomplish the task.

Cut marks have been noted on a wide variety of taxa representing all vertebrate classes. Mid- to large-size mammals appear the common target. Examples, however, of much smaller and less common prey animals as determined through the presence of cut marks on their elements include fish (e.g., Willis et al. 2008; Jurgens

2010), tortoises (e.g., Blasco 2008), birds (e.g., Cassoli and Tagliacozzo 1997; Steadman et al. 2002; Haury 2008; Blasco and Peris 2009; Bochenski et al. 2009), rodents (e.g., Johnson 1987), and rabbits (Hockett 1994; Lloveras et al. 2011). Generally, little comparison has been made to determine whether differences or consistencies exist between the taxa in their cut marks and what that might mean methodologically in recognizing cut marks or behaviorally in creating them.

Merritt (2012) examined whether cut marks could be an indicator of tool type, experimentally butchering large (cow) and small (goat) carcasses. He measured the width and depth of cut mark cross sections. While his analysis was mostly in the framework of carcass size (by large or by small mammal), he noted that cut marks on cow elements tended to be deeper and wider than on goat elements. He attributed the difference to the greater effort required in butchering a large carcass.

Bello et al. (2009) provided a different experimental perspective but a similar interpretation of differences in cut marks across taxa. Using three-dimensional reconstruction of marks, they compared experimentally generated cut marks on roe deer with cut marks on a small variety of large mammals from a Lower Paleolithic site. They interpreted the difference between the experimental and archeological sets of cut marks to indicate a greater effort or force needed in butchering a large mammal carcass, variation in the angle of the cut, and robustness of these early hominins. The underlying assumption in both experiments would appear to be that interspecies cut marks would be the same, exhibiting the same features, and therefore, behavioral inferences could be made.

The recent works by Boschin and Crezzini (2012) and Schmidt et al. (2012) also used three-dimensional images of experimental and archeological cut marks and morphometrics to explore discriminating between marks made by metal knives and those by stone tools. The profiles of the cut marks made by metal versus stone showed different patterns, as did those of unmodified chert flakes and bifaces. While Boschin and Crezzini (2012) used various statistical analyses to confirm the morphological findings, they were not able to discriminate between flakes and retouched tools within the stone tool category. Schmidt et al. (2012) used profile images to discriminate within the stone tool category. Neither study explored interspecies cut marks.

Bunn (1994) reported multiple mammalian taxa with cut marks in Koobi Fora assemblages, but no morphological or interspecies comparative analyses of the cut marks were done. This early study was instrumental in arguing

that even in the absence of stone tools, bones exhibiting cut marks were evidence of hominin activity. On the basis of that assertion, Bunn (1993) expanded on foraging strategies used by these early peoples in acquiring carcasses and different strategies of carcass utilization.

A number of studies (e.g., Lyman 1992, 2005; Lupo and O'Connell 2002; Egeland 2003; Domínguez-Rodrigo 2003; Domínguez-Rodrigo and Yravedra 2009) have looked at cut mark frequencies or percentages across mammalian taxa. Carcass size appears to play a major role in frequency differences, but frequency differences across sites for the same taxon also occur. These studies, however, neither address the morphology of the cut marks nor provide a comparison of cut marks among the taxa represented.

Frequency of cut marks also was examined by tool material type within an experimental approach using unmodified flakes as the tools (Dewbury and Russell 2007). Obsidian flakes were found to leave fewer cut marks on bones than chert flakes. Sharpness and durability were influencing factors in how tools were used. Another experimental study use unmodified flakes to examine tool attrition (Braun et al. 2008). While the creation of cut marks apparently was not linked with edge attrition, the occurrence of tool edge attrition was higher with skinning and disjointing activities.

Various other studies (Potts and Shipman 1981; Abe et al. 2002; Lupo and O'Connell 2002; Lyman 2005; de Juana et al. 2010; Schmidt et al. 2012) often employ experimental methodologies that utilize a variety of lithic tools ranging from unmodified flakes to bifaces and hand axes. Lithics are sparse with the Wisconsin mammoths, with only a few found at two of the sites. The lithic assemblage at Schaefer consists of an unmodified flake and a broken biface edge while two small bifaces, an unmodified flake, and a chopper come from Hebior (Overstreet 1998; Overstreet and Kolb 2003). These lithics have been subjected to microwear analysis. Those from Schaefer do not exhibit any wear patterns, while the two bifaces from Hebior have wear patterns of meat and hide polish, indicating their use in butchering activities (Yerkes and Weinberger 1998; Overstreet and Kolb 2003).

The most common butchering tools found at Cooper are large flake knives that display resharpening on the dorsal surface (Bement 1999). These flake tools create cut marks with sharp troughs and minimally striated walls (Schmidt et al. 2012). Bifaces generally leave cuts with broader troughs and walls displaying multiple striations. Overlapping morphologies occur when the edges of flake knives dull and microflaking from use mimics bifacial

flaking. The differences in tool assemblages and generally broader troughs of the cut marks on the Schaefer and Hebior mammoths and tightly constrained troughs of the Cooper marks are concordant with these findings. This situation implies that the types of tools being used have a greater influence on the micromorphology of cut marks than either size or species of the carcass being butchered.

The results of this analysis demonstrate a consistency in incised marks across the two taxa (Table 2). The marks on the Wisconsin mammoths identified as mark type 1 are not outliers in any of the statistical tests and share the same characteristics as the cut marks on the Cooper bison bones.

CONCLUDING REMARKS

Research is exploratory, and mark size, shape, and variation were examined. The focus is on one mark type (incised mark) that overlaps in the two datasets. Based on these two datasets representing different taxa and time periods, initial findings are:

1. Incised marks have a consistency in mark production that can be identified by a series of microfeatures that characterized it.

2. Mark location or placement appears to influence mark length.

3. While mark width can be categorized as narrow or broad, in general, mark width is constrained.

4. The number of strokes per mark versus length or width was not significant.

5. Which wall was the steep-sided wall for incised marks in terms of length or width was not significant.

6. The shape of mark ends varied significantly by length across taxa, with the shortest and narrowest generally having feathered ends.

7. Mark orientation appears to influence the length of a mark.

8. The condition of the carcass (fresh or stiffened) and the types of tools used appear to have a much greater influence on cut mark micromorphology than either carcass size or species.

Cut marks are accidental occurrences, by-products of carcass processing. While their absence on an element does not necessarily mean the bone did not undergo processing, their presence, type, location, complexity, and intensity provide clues to the processing strategy and tasks involved. At both the Wisconsin localities and at the Cooper site, these marks appear primarily on a highly select category of elements, and then only on particular elements. Certain parts of the carcasses are being targeted: for the Wisconsin mammoth primarily the limbs, and

for Cooper bison the ribs and vertebrae (Johnson 2007b; Johnson and Bement 2009). Very directed activities are taking place within limited task parameters.

This morphometric approach to marks on bones crosscuts time and space boundaries and should be applicable to any bone assemblage. This approach reduces subjectivity and reliance on only one or two microfeatures to determine hominid intervention by examining statistically a suite of internal and external variables. The central question in dealing with any bone assemblage is whether or not marks are caused by hominid agency (e.g., Binford 1977, 1981; Bunn 1983; Shipman 1989, 1997; Haynes 2002; Johnson 2006, 2007b). The approach utilized here can be useful in addressing that central question. And if the marks are the result of hominid behavior, then questions about that behavior can be addressed, regardless of age or lithic context.

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