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A new protocol to differentiate trampling marks from butchery cut marks

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ABSTRACT

Microscopic signatures have previously been used to emphasize the similarities of butchery and trampling marks. The experimental background applied to differentiate both types of marks has been rather limited and authors have sometimes reached conflicting conclusions. This is partly due to methodological reasons: some authors have used very high magnification to examine microscopic features, whereas others have relied on more reduced magnification. Likewise, some experiments have exposed bones to trampling for reduced periods (minutes) whereas others have used longer time periods (hours). The present study stresses that the use of a scanning electronic microscope is not practical for identifying the impact of butchery and trampling marks in complete bone assemblages. It also emphasizes that previous studies have not addressed all the possible variables that could potentially be used to discriminate these marks, nor have they quantified the morphological patterns of each type of mark. Here we present a multivariate analysis of more than a dozen variables and show that butchery and trampling marks have very distinctive microscopic morphology. We advocate the use of a low magnification approach ($\leq 40\times$), which can enable the analysis of complete assemblages using either hand lenses or binocular lenses. We also show the morphological criteria that differentiate butchery cut marks made with simple and retouched tools. We show that whereas complete discrimination of marks is impossible due to some degree of overlap, the list of criteria derived through multivariate analyses can be confidently used to correctly differentiate butchery and trampling marks in more than 90% of cases.

1. Introduction

During the 1980s, abundant literature unveiled the discovery of natural marks caused by sediment abrasion on bone surfaces through various processes (namely, trampling) that could mimic butchery marks (see review in Olsen and Shipman, 1988). Most researchers agreed that several of the microscopic characteristics of cut marks could also be documented in trampling marks. Since then, research on these abrasive processes has decreased, which is surprising given that the criteria proposed to differentiate trampling from butchery cut marks were heterogeneous, and some of them were in disagreement with one another depending on the author. For example, Behrensmeyer et al. (1986) argued that microscopic features alone were not enough to differentiate human-generated cut marks from trampling marks. The anatomical occurrence of marks on bones was thus crucial. This was supported by Andrews and Cook (1985), Fiorillo (1984) and Oliver (1984). Other authors (e.g., Olsen and Shipman, 1988) argued, in contrast, that their trampling experiments failed to produce any marks of sufficient depth and of proper morphology to be mistaken for normal butchery cuts after careful inspection.

These differences in the perception of similarity (or dissimilarity) of both types of marks has as much to do with experimental protocols as with the actual overlap of their morphological features. Olsen and Shipman (1988) claimed that most of the striations created by experimental trampling were smooth-walled and lacked the internal parallel lines associated with known cut marks. This is in contrast with Beherensmeyer et al.'s (1986: Figs. 3e,f) replication of trampling marks with internal microstriations, and similar features reported by Andrews and Cook (1985; Fig. 6e), Fiorillo (1984; Figs. 9b,d) and Oliver (1984; Figs. 21c,e–g). Andrews and Cook's (1985) and Oliver's (1984) samples are strictly observational and not experimental. Regarding this, Olsen and Shipman (1988, p. 536) objected that "they are perhaps the most subject to error and are the most dependent on assumptions. This is because, without direct observation of the activities involved, proof that trampling was an important taphonomic factor depends upon accurate reconstruction of the post-depositional environment over time. In addition, all other known causes of sedimentary abrasion must be eliminated before surface modification can be confidently attributed to trampling *per se*". However, Behrensmeyer et al.'s (1986) experimental sample shows that after 3 min of trampling, cut

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marks could undergo a loss of internal striae, which are hard to preserve, and even washing could eliminate them. This applies also to trampling marks that are exposed for a prolonged period to the abrasive process of trampling. Olsen and Shipman's experiment consisted of prolonged trampling for 2 h. Therefore, it is not surprising that most of the resulting marks lack internal striations. In contrast, short-time exposure to trampling can produce marks with internal striae, which if undisturbed could potentially mimic cut marks. These marks were described by Behrensmeyer et al. (1986) as V-shaped marks that have rounded basal cross-sections and rounded outer edges. These trampling marks containing internal striae could be hard to differentiate from cut marks. At the same time, trampling marks without internal striae could be hard to differentiate from cut marks that have lost theirs.

The message from the use of the literature from the 1980s (and the experience of the senior author over two decades of exchange with colleagues) is that taphonomists interpret many cut marks and trampling marks subjectively given the lack of an accepted protocol or diagnosis for the latter beyond the following criteria: trampling marks frequently occur as multiple patches of grooves showing diverse orientation, in contrast with the more discrete orientation and smaller number of cut marks; and trampling marks do not appear preferentially on certain anatomical areas, as cut marks frequently do, but rather are randomly located on bones. These criteria have serious problems. First, intensive trampling generating multiple randomly-oriented striae is probably a minor process in site formation. Occasional episodes of trampling on bone that occur once or very few times (far less than what is reproduced in several-minute or several-hour experiments) are probably more common. Given the destructive effect that 3-min trampling experiments have on the microscopic diagnosis of trampling and butchering marks, it could be argued that the probably less-destructive effects of more brief (equivalent to few seconds) episodes of trampling remain insufficiently explored experimentally. Secondly, it is true that cut marks occur more frequently in certain areas subjected to determined butchering behaviors. However, many of these areas, such as certain epiphyses or meta-diaphyses are subjected to density-mediated attrition and may be under-represented in many faunal assemblages. Likewise, many cut marks also occur on long bone shaft surfaces in a non-predictable manner (Domínguez-Rodrigo and Barba, 2007). Using the anatomical location as an attribute to differentiate these marks from trampling marks is not useful.

Therefore, microscopic features could be potentially preferred over mark location as a safer way of identifying marks. The use of the criteria stressed by the available literature, though, is also somewhat problematic because of their limited applicability. Most studies of the microscopic features of these marks use SEM and high magnifications. Behrensmeyer et al. (1986) used criteria that were detected using up to 400× magnification. Andrews and Cook (1985), while suggesting a broad range between 20× and 500× magnification, used even higher power to examine some of the microscopic features of marks (up to 750×). Olsen and Shipman (1988) suggested that because sedimentary abrasion is generally very fine, it is best observed with a microscope at magnifications between 25× and 500×. The use of SEM is time consuming and expensive and can thus be applied only to a selected number of specimens but not to a whole assemblage, depending on the resources available. Thus one must be able to justify how well the selected sample represents the whole assemblage.

Another pitfall is that in order to understand trampling mark morphology and differentiate it from cut mark morphology, it is necessary to understand the range of forms that cut marks can show. Most butchery experiments have been performed with non-modified flakes. This leaves us with some questions: how similar or different are the resulting cut marks using simple flakes from those made with retouched flakes? How much overlap between trampling marks and butchery marks varies depending on the type of cut mark?

The present work aims at integrating all these questions into the same experimental program in a practical way, which does not depend on the use of complex high magnification equipment and, therefore, can be applied to complete assemblages. This approach contrasts with previous research, which was mainly descriptive, by being more analytical and quantifying characteristics in a mathematical way. This reduces the subjectivity of description to a minimum. It is not known how many of the features previously reported as overlapping between trampling marks and cut marks are predominantly represented in trampling or butchering processes and how many of them are marginal. The present study aims to increase the number of referential analogues on cut mark diversity (using different types of tools) and trampling/sediment abrasion mark diversity (using shorter and more prolonged times of exposure to trampling, depending on sediment type: fine-grained sand to gravel). In contrast with previous experimental studies, we use a multivariate approach, in which several more variables involving microscopic (observable at ≤40×) and semi-microscopic criteria (most of them new) are used together in order to understand the ranges of variation of each mark type and the degree of overlap among different types of marks. Ultimately, this has helped us point to those diagnostic criteria which can effectively used to discriminate marks. So far, the only microscopic feature that was most frequently used to identify butchery marks was the presence of internal striae within the groove (Olsen and Shipman, 1988), but it is safe to claim that given the difficulties in the preservation of these microstriations (see Behrensmeyer et al., 1986), most prehistoric butchery marks may lack these microscopic features. Their identification will thus have to rely on a combination of other features, several of which should, presumably, be more frequently associated with the use of stone tools than with the abrasive power of sediments.

This work uses a long list of variables to determine which ones are actually discriminating and under what processes they can help differentiate cut marks from trampling marks both in the presence and absence of internal microstriations. In the present study, we add more support to previous protocols on mark identification that advise against the identification of marks by the naked eye alone. The features that we present here and which can sometimes be referred to as quasi-macroscopic (i.e., spotted by the naked eye but securely identified with the aid of low magnification) will need only low magnification to be confirmed. We join the group of researchers who argue that no bone surface modification can be properly identified without the use of some degree of magnification (Blumenschine et al., 1996).

2. Method and sample

The trampling experiments involved the joint use of two variables: sediment type and time of exposure to trampling (Fig. 1). Five sediment types were selected: fine-grained sand (0.06–0.2 mm), medium-grained sand (0.2–0.6 mm), coarse-grained sand (0.6–2.0 mm), a combination of the previous sand types over a clay substratum, and gravel (>2.0 mm). In each sedimentary context, trampling was carried out in two experimental sets with different times, reproducing brief (10 s) and prolonged (2 min) exposure to trampling. Trampling was made by the three junior authors (with different body weights) wearing shoes with esparto grass soles. Bones from deer (long bones and ribs) were used for the trampling experiment. These deer were obtained from legal organised hunting parties, after which

Fig. 1. Experimental area with four different types of sand.

carcasses were butchered with metal knives. In order to help degrease them, bones were buried after butchery for a few weeks and then boiled in a neutral solution of water and soap to be cleaned, after having been broken into geometric sections with a small electrical hand saw to remove the marrow without leaving surface marks (Fig. 2). The use of an electrical saw enabled us to break the bones without leaving surface modifications on them as would occur if using hammerstones. Then, in order to isolate butchery marks from trampling marks, a careful inspection of the bone surfaces using hand lenses under a strong light was carried out jointly by three of the authors to detect cut marks. These were isolated by coloring them with permanent markers. After that, bones were used for trampling experiments. A total of 220 bone fragments from 45 elements (ribs and long bones) were used. Many inconspicuous (e.g., hardly perceptible without the use of magnification) abrasion marks were observed, but only those that were more noticeable to the naked eye, and therefore more prone to be mistaken with cut marks, were selected. This resulted in 251 conspicuous (e.g., identifiable without the use of magnification) marks that entered the multivariate analysis. This experimental set was compared to a sample of 246 cut marks made with simple flakes from another experiment consisting of the butchery of four goats, and 105 cut marks made with retouched flakes from the butchery of a goat and a young cow. These sets came from the experimental archaeology program of the Paleolithic Archaeology course taken by students at Complutense University (Domínguez-Rodrigo and Barba, 2005). The number of marks analysed renders the sample optimal for the multivariate statistics applied, which require a minimum of 10 cases per variable used to accurately estimate the amount of variance explained by factors. The sample fits this condition by more than twice the number of cases required per variable.

Marks were first identified by the naked eye and then inspected under a strong light (60 watt) with the aid of hand lenses. The features documented with such low magnification were then confirmed with the aid of a binocular microscope with magnifications of 20×–40×. The images were transmitted directly to a computer and processed with Motic Image Plus 2.0 software. Every single mark identified was inspected by all the authors to confirm each variable analysed. In the few cases where there were disagreement in the identification of any of the variables, those marks were excluded from the analysed sample.

Fig. 2. Some of the bones used for the experiments after defleshing (A) and after cleaning, sectioning and screening of bone surface modifications caused by butchery (B).

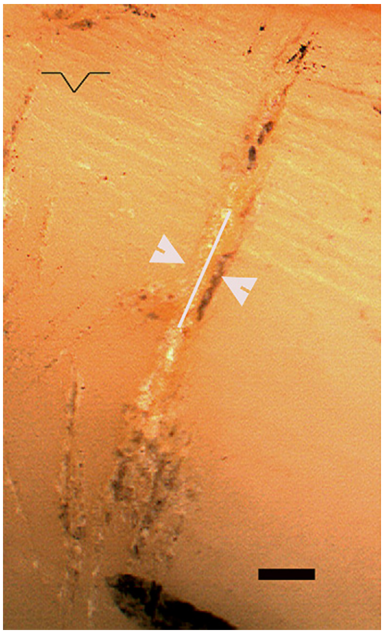

Fig. 3. A set of cut marks made with simple flakes. The longest cut mark shows the typical V-shape (with the white line marking the bottom edge that connects both walls) as can be better seen in the section profile drawn in the upper left corner of the image. Arrows point to the edges of the groove shoulders. Scale = 500 microns.

A list of variables has been compiled based on the properties of marks that could be easily detectable with the use of low magnification (10×–40×). This list includes morphological properties as well as structural features both inside the grooves and outside of them but in clear association with the grooves. These variables are:

1. Trajectory of the groove. Marks can show a straight trajectory (a), a curvy one (b) or a sinuous one (c). This applies to most of the outline of the mark, excluding the presence of barbs at the end of the mark. Butchery marks are commonly straight grooves (Fig. 3). In some cases, the abrasive marks created by sediment grains show a somewhat sinuous trajectory in part of the groove due to the rolling of the grain and the use of different edges of the grain for abrading the bone surface. Some apparently straight trampling marks, when observed under magnification, show trajectories that are not perfectly straight but are rather somewhat wavy (Fig. 4).
2. Presence (a) or absence (b) of a barb. In some butchery marks, a barb can be observed at the end of the straight groove, defined as a shallower end of the groove slightly curved to the side in the form of an open hook. Testing how frequent this feature is in cut marks and in trampling marks can be potentially important, since it has also been observed in the latter (Fig. 5).
3. Orientation of the mark, relative to the axis of the bone. The orientation can be parallel (a), perpendicular (b) or oblique (c) to the axis of the bone. Trampling marks, in theory, should show no preference in orientation, whereas butchery marks should be more frequently oriented obliquely or perpendicularly to the axis of the bone (Behrensmeyer et al., 1986; Olsen and Shipman, 1988).
4. Shape of the groove. The shapes used are: narrow V-shape (a), and wide V-shape (_/) (b). The former is understood as either V- or _/-shaped but either almost as deep as it is wide, or deeper than it is wide; the latter is understood as an open groove with a broader horizontal base and, therefore, substantially wider (by an order of magnitude >2×) than deeper.
5. Number of conspicuous grooves per bone specimen. It has been mentioned that cut marks occur in lower numbers per specimen than trampling marks (Oliver, 1984; Behrensmeyer et al., 1986; Olsen and Shipman, 1988).
6. Symmetry of the groove: the section and both sides of the groove can be symmetrical (a) or asymmetrical (b). The tilting of a stone tool during use can create asymmetrical grooves, and so can certain sediment particles during bone abrasion (Andrews and Cook, 1985).
7. Shoulder effect and associated shallower striae. Here we define the term as the striae occurring in association with the main groove in a distance not farther than 0.2 mm from the edge of the groove. For this type of analysis, a binocular lens with measuring capability is preferred. These striae frequently are shallow striations occurring parallel to or intersecting with the sides of the groove. They can be present (a) or absent (b) and have been documented in trampling marks (Fig. 6) and cut marks (Fig. 7).
8. Presence of flaking on the shoulders of the groove. The presence (over more (a) or less (b) than one-third of the trajectory of one or two shoulders of the groove) or absence (c) of flaking on the shoulders of the groove can be related to the morphology of the abrasive agent: the bigger and less straight the edge of this agent the bigger the chance that such flaking would appear. Flaking here is defined as not a random occurrence of a flaking dent such as those produced in isolated hertzian cones, but as a continuous series of exfoliation of the shoulder edge, which can occur on part of the trajectory of the shoulder or on most of it (Fig. 8).
9. Extent of the flaking of the shoulder. The extent of the flaking could also be indicative of the abrasive agent. The category of

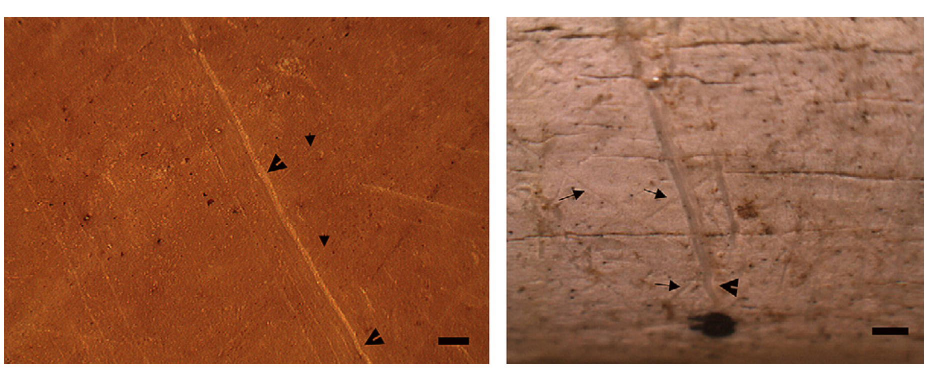

Fig. 4. Two examples of trampling marks. Notice the broad shape of the groove, with an irregular winding shape of the trajectory, indicated by large arrows. Small arrows show some of the oblique striae connecting to or crossing the main groove. Notice the microabrasion on the bone surface. The image on the left also shows multiple shallow loosely-spaced striae running parallel to the main groove. Scale = 500 microns.

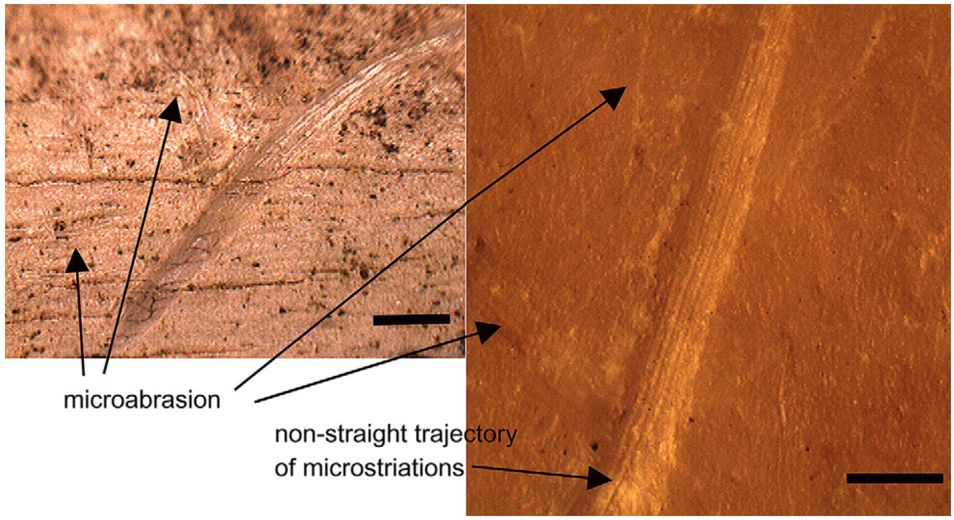

Fig. 5. Typical trampling marks showing a broad and shallow groove shape with internal microstriations. The mark on the left has a curvy ending in the form of a barb. Notice the microabrasion on various parts of the specimens' surfaces and the irregular shape of the microstriations in the mark on the right. The lack of shoulder flaking and the sharp shoulder edge were also commonly documented in the trampling marks in the experiment. Scale = 500 microns.

the flaking can be defined as long (a) when it occurs over a minimum of one-third of the trajectory of the groove and short (b) when it is shorter than one-third. Approximate estimates can be made with hand lenses.

10. Striae overlapping or running across the main groove with an oblique angle: present (a) or absent (b). These striae are frequently shallow in trampling marks (Fig. 5).
11. Internal microstriations. Defined as present (11a) or absent (11b) and observable under 40×.
12. Microstriation trajectory. Defined as continuous (a) when it extends along all the trajectory of the groove or discontinuous (b) when the microstriations are interrupted at more than one instance inside the groove. A tool is more likely to create continuous microstriations given that it creates uniform friction in its contact with bone. A trampling mark is more likely to created discontinuous microstriations if friction forces the sediment particle to move inside the groove.
13. Shape of microstriation trajectory. Defined as straight (a) or irregular (b), the latter including any other shape (curved, sinuous, combination of forms) (Fig. 5).
14. Location of microstriations. On the walls of the groove (a), on the bottom (b) or on both (c).
15. Length of the main groove (in mm).
16. Associated shallow striae (microabrasion) on the bone specimen away from the main groove (contextual approach) (Pickering et al., 2004, 2008): absence (a) or presence (b). Andrews and Cook (1985) claimed that these could only be detected with magnification >75×. We only tally presence or absence when identified under magnification <40× since in our experience we have documented that such striae can be detected most of the time under this magnification. These striae are very shallow and often not easy to perceive if one is not looking for them explicitly. They are caused by the sediment grains of sandy gritty soils which are part of the substrate where trampling takes place. Usually the sediment particle that is used for creating trampling marks is in a substrate of many more sediment particles of various sizes that create this background noise in the form of abrasion striae (Fig. 9). Cut-marked bones subjected to trampling can also show these striae.

In our analysis, three types of statistical analyses were applied to the data. Differences in the variance values of dimensional variables were analyzed through factorial ANOVA (using general linear models). In all cases, Levine's test was applied beforehand to test for homogeneity of variance in the samples used. Data were treated for normality and homocedasticity. Dimensional values with a non-normal distribution, requiring transformation, were log-transformed and then standardized.

In order to treat all the variables together, to understand their inter-relation and the weight that each of them has on the common variance separating each type of mark, a categorical principal components analysis (CATPCA) was carried out following the optimal scaling procedure. The selection of CATPCA over a factor analysis or a regular principal component analysis is supported by the mixed nature of the set of variables that include two types: numerical (two-dimensional variables) and

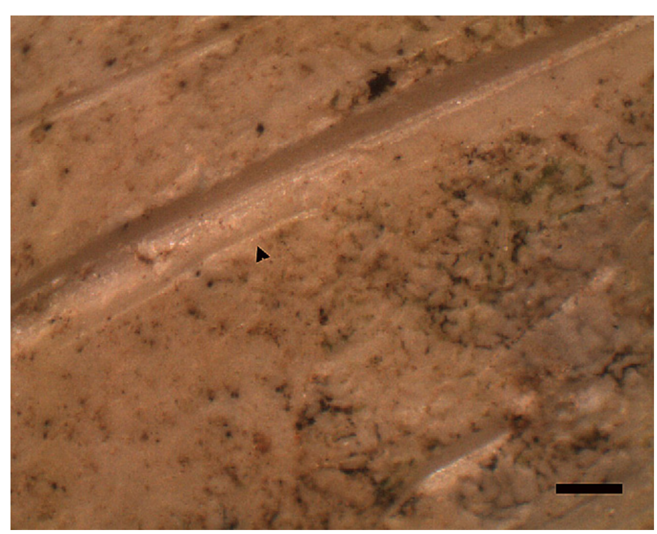

Fig. 6. Trampling mark with shoulder effect. The shoulder striation is shallower than the main groove and non-straight in its trajectory. Notice the internal microstriations and the sharp edges of the shoulders. Scale = 500 microns.

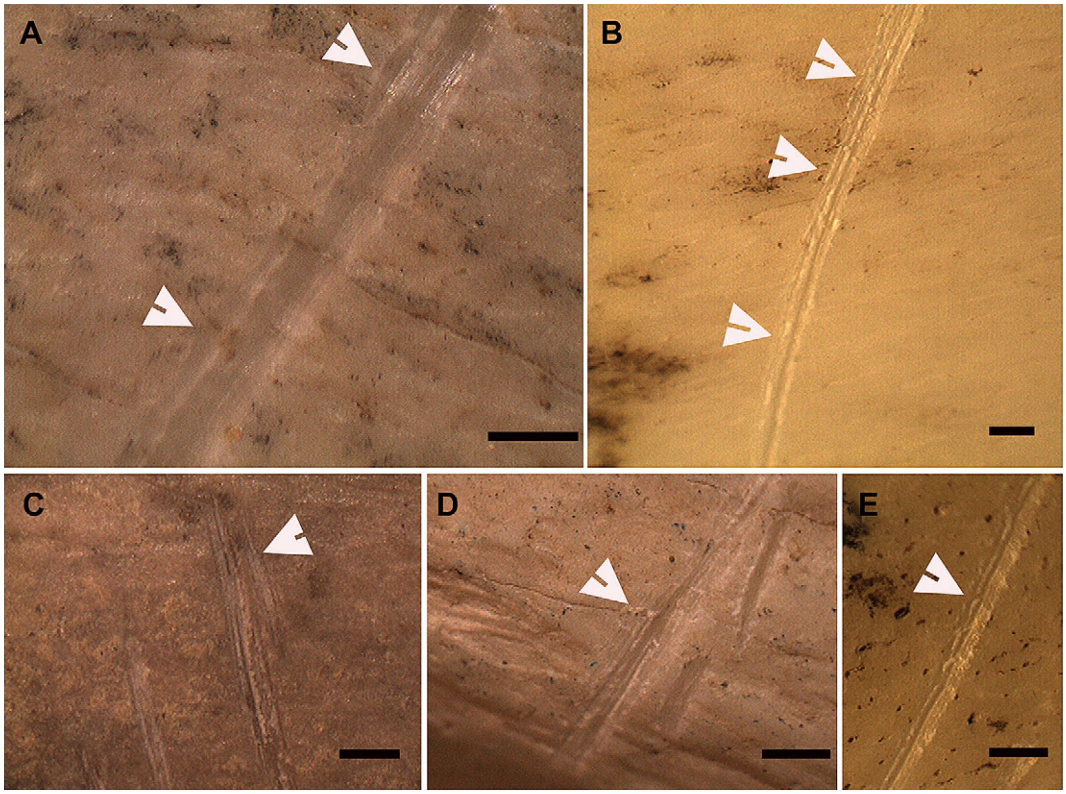

Fig. 7. Multiple examples of cut marks made with retouched stone flakes. Notice the broad section of the grooves and the presence of shoulder effect (white arrows), which can be nearly as deep as the cut mark (A, C, D) and which can appear in the form of multiple parallel striae (B, C, D). Notice also the double groove in some of the cut marks (B, C, D). Scale = 500 microns.

categorical (14 out of 16 variables). This procedure simultaneously quantifies categorical and numerical variables while reducing the dimensionality of the data. Variables were optimally scaled using SPSS software. CATPCA does not require that the sample is normally and linearly distributed or homocedastic. The discretization method selected was principal variable normalization, since the aim was to maximize relations among the variables selected.

Finally, a logistic regression analysis was made to perform pairwise comparisons of marks in order to avoid the more intense overlap of characteristics when comparing the three marks at the same time. A logistic regression can be used to determine if a discrete binomial criterion variable is influenced by other predictor variables (categorical and numeral) and to what degree. The method selected to enter variables in the regression was step by step according to their sigma value using the Wald statistic.

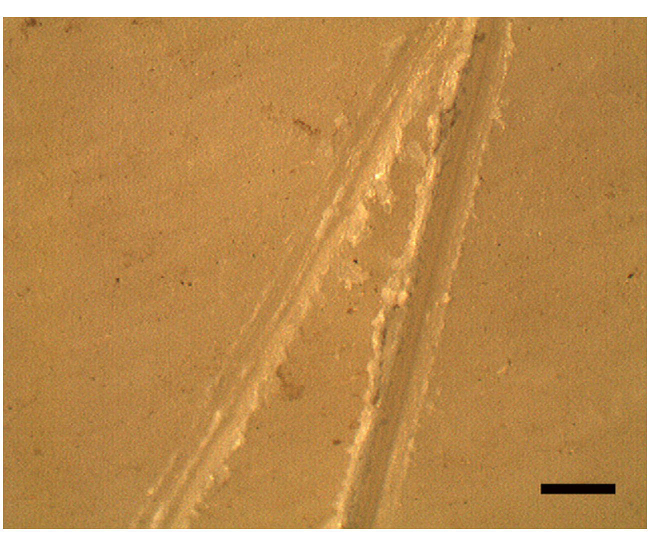

Fig. 8. Cut marks made with retouched stone flakes showing intensive flaking on the edges of one of the shoulders of each mark. Scale = 500 microns.

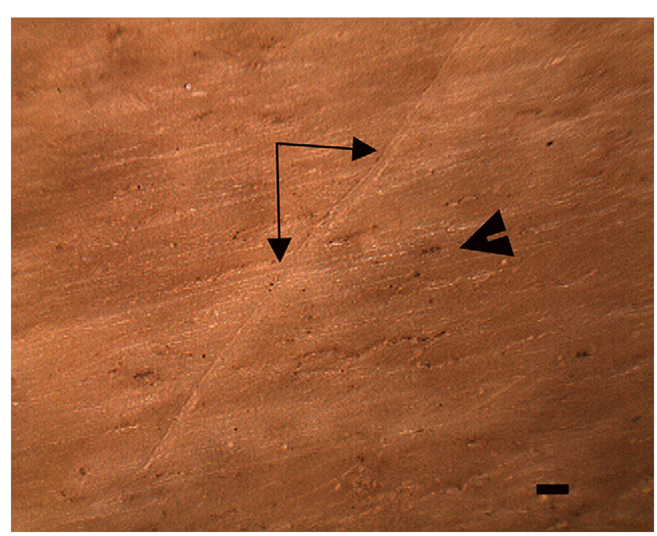

Fig. 9. Trampling mark showing sinuous trajectory (indicated by arrows) and with most of the bone surface covered in multiple parallel very shallow striae (micro-abrasion). Scale = 500 microns.

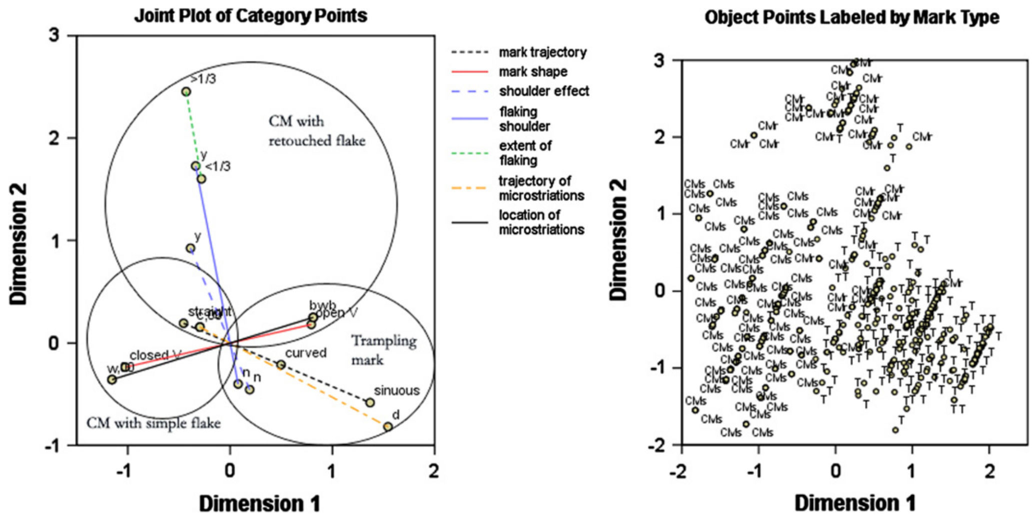

Fig. 10. Left: Joint plot of category points of the seven variables selected in the two-dimension solution using CATPCA. Intra-variable categories are also shown. Method used: principal variable normalization. Y, yes (present); N, no (absent); W, microstriations located on the wall of the groove; B, microstriations located at the base of the groove; WB, microstriations located both on the wall and at the base of the groove; D, discontinuous trajectory of microstriations; C, continuous trajectory of microstriations; >1/3, major presence of flaking on the shoulder edge; <1/3, minor presence of flaking on the shoulder edge. Oval and circle shapes show the space comprised by the intra- and inter-variable categories according to mark type. Right: plot of dimensional distribution of each mark type in the sample used for the present study, based on the variable distribution shown in the right figure. Three discrete clusters of mark distribution can be observed. CMs, cut marks made with simple flakes; CMr, cut marks made with retouched flakes; T, trampling marks.

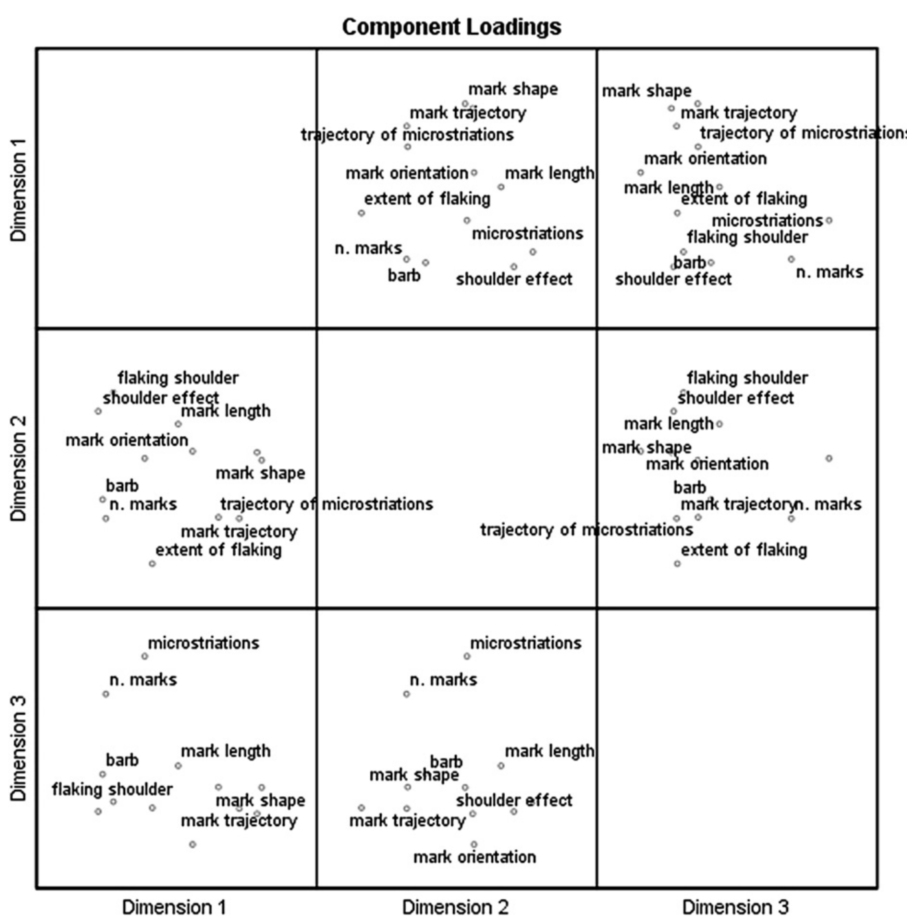

Fig. 11. Three-dimension distribution of the variables selected by CATPCA analysis. See text for explanation of each dimension.

Table 1
Variables in the equation discriminating trampling marks to butchery marks made with simple flakes.

		B	SE	Wald	df	Sig.	Exp (B)	95.0% CI for Exp (B)	
								Lower	Upper
Step 6	Trajectory	−3.234	.766	17.809	1	.000	.039	.009	.177
	Orientation	−2.336	.808	8.361	1	.004	.097	.020	.471
	Shape	−12.344	2.259	29.866	1	.000	.000	.000	.000
	Presence microstriations	3.272	1.395	5.502	1	.019	26.374	1.713	406.117
	Trajectory microstriations	−7.182	1.979	13.171	1	.000	.001	.000	.037
	Location	2.979	.972	9.391	1	.002	19.676	2.927	132.286
	Constant	27.973	4.990	31.427	1	.000	1,407,292,360,028,395		

Variables entered on step 6: trajectory, orientation, shape, presence of microstriations, trajectory of microstriations, location of microstriations.

3. Results

In the trampling experiment, sediment type played a role in the number of conspicuous marks identified by the naked eye (percentages are for the total number of marks lumping all sediment types together): fine-grained (3.5%), medium-grained (14.7%), coarse-grained (31%), the combined sandy sediment (12%) and gravel (39%). There is a positive correlation between sediment type and number of marks: ($r = .73$, $p = .052$). This correlation becomes stronger and significant if we remove the mixed sediment set ($r = .95$, $p = .043$). Time of exposure to trampling also influences the total number of marks created. The 10-s experiments account for only 16% of the marks created, whereas the 2-min experiments created the remaining 84%. There is also a strong correlation between time of exposure and number of marks ($r = .97$, $p = .033$).

For the multivariate statistical analysis comparing trampling and butchery marks, the variable set selected excluded two variables exclusively documented in trampling processes (presence of oblique shallow striae crossing the principal mark, and micro-abrasion) since these features were not documented in the cut-marked sample given that this sample was not subjected to trampling. Including these variables would have fatally biased the analysis of variance given their overwhelming representation in the trampling experiments. Since a cut-marked bone subjected to trampling would equally have shown these features, rendering it indistinguishable from a non-cut-marked trampled bone, the exclusion of these variables was necessary for the correct identification of the weight of each of the remaining variables in the distribution of variance.

When using CATPCA with the selected set of variables, the resulting two-dimensional outcome showed a solution that explained only 50.4% of variance (Cronbach's alpha = .92; Eigenvalue = 5.8). The influential variables in each dimension were determined by selecting those that showed more than 0.5 in the loading scores. The low resulting explained variance also showed that when trying to differentiate among trampling marks, cut marks made with simple flakes and cut marks made with retouched flakes, there was an important amount of overlap in several of the variables used and the resulting range of variation for each mark type. A two-dimensional solution showed that despite this overlap, some criteria seemed to be able to differentiate an important number of the three mark types (Fig. 10). Dimension 1 is determined by the following variables with high-loading scores: shape of the groove (.90), location of microstriations (.87), trajectory of the mark (.74), and trajectory of microstriations (.6). Cut marks made with simple flakes more commonly had a closed-V- or closed-_/-shape, whereas those made with retouched flakes or trampling showed an open-_/ pattern. A frequent characteristic of trampling marks is that they may present a sinuous trajectory. Cut marks made with both types of flakes are usually straight or, less frequently, somewhat curvy depending on the degree of curvature of the bone surface. Virtually all cut marks showed microstriations, whereas the presence of these was more variable in trampling marks, especially in experiments where bones were subjected to trampling for 2 min. Microstriations in cut marks were straight and continuous, whereas they were often discontinuous or curvy in trampling marks (Fig. 5). The location of microstriations is closely related to the shape of the groove. As mentioned previously, most cut marks created with simple flakes showed a closed-V-shape, so under 40×, microstriations were identified on the walls of the groove. Trampling marks had an open _/-shape with a wide base. Given that most of them were shallow, under 40× no microstriations were identified on the walls and most of them appeared at the base. Cut marks created with retouched flakes were also commonly open _/-shaped but proportionally deeper than trampling marks, and microstriations could be identified more frequently both at the base and walls of the groove when using magnification <40×.

Dimension 2 was determined by the following variables (with their corresponding loading scores): presence of flaking on the shoulder of the groove (.79), extent of the flaking (.71) and presence of shoulder effect (.53). Whereas the variables involved in Dimension 1 seem to be effective at differentiating between cut marks (namely, those made with simple flakes) and trampling marks, the variables in Dimension 2 indicate the main features that distinguish cut marks made with retouched flakes from the other marks. For instance, the modification of the shoulder of the mark can be used to effectively differentiate cut marks made with retouched flakes from the other marks. The former have a higher incidence of

Table 2
Variables in the equation discriminating trampling marks and butchery marks made with retouched flakes.

		B	SE	Wald	df	Sig	Exp (B)	95.0% CI for Exp (B)	
								Lower	Upper
Step 3	Trajectory	−2.043	.398	26.413	1	.000	.130	.059	.283
	Shoulder	2.652	.430	38.065	1	.000	14.175	6.105	32.912
	Flaking	2.503	.610	16.849	1	.000	12.222	3.699	40.385
	Constant	.827	.516	2.571	1	.109	2.287		

Variables entered on step 3: trajectory, shoulder, flaking.

Table 3
Variables in the equation discriminating butchery mark types.

		B	SE	Wald	df	Sig	Exp (B)	95.0% CI for Exp (B)	
								Lower	Upper
Step 2	Shoulder	1.697	.316	28.834	1	.000	5.459	2.938	10.144
	Flaking	1.718	.347	24.559	1	.000	5.576	2.826	11.001
	Constant	−1.599	.264	36.832	1	.000	.202		

Variables entered on step 2: shoulder, flaking.

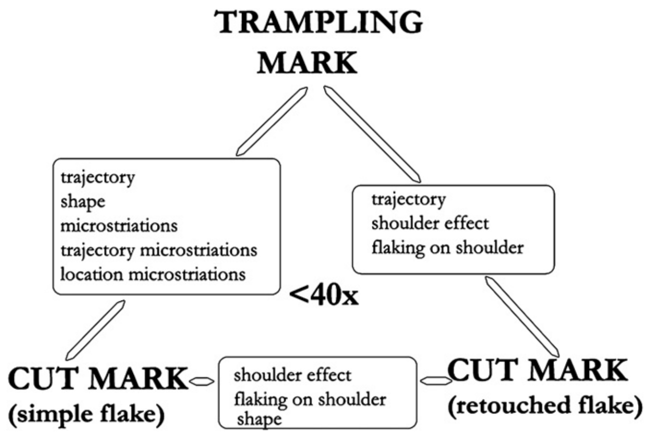

Fig. 12. Summary of variables selected through CATPCA and logistic regression analyses to discriminate between mark types using a $<40\times$ identification method.

shoulder effect associated with the main groove and a higher frequency of flaking of the shoulder (given the irregular shape of the flake edge). This flaking, in contrast with the marginal occurrence of some flaking either in trampling marks or cut marks made with simple flakes, may extend beyond one-third of the groove edge. This has not been reported for trampling marks in the present study.

In order to increase the amount of variance explained, a multidimensional solution involving three dimensions was obtained using a scree plot with eigenvalues higher than 1. This solution selected the same variables for Dimension 1 (with the same loading scores) and Dimension 2: presence of flaking on the shoulder of the groove (.81), extent of the flaking (.72) and shoulder effect (.51). Dimension 3 was determined by presence of microstriations (.96) and a number of conspicuous marks (.71). This explained 65% of the variance of the sample (Cronbach's alpha = .94; Eigenvalue = 8.3) (Fig. 11). Dimensions 1 and 2 more effectively distinguished among cut mark types, better than separating cut marks from trampling marks with microstriations. Dimension 3 separated the three marks more effectively. This is partially due to the inclusion of two variables that discriminated marks better after the other variables had initially separated the sample.

A more accurate discrimination could be obtained if marks were differentiated pairwise. The problem of limited common variance detected in the CATPCA analysis was due to the overlap in some features between cut marks made with retouched flakes and trampling marks. If comparing marks in pairs (trampling vs. cut marks made with simple flakes, trampling vs. cut marks made with retouched flakes, and both cut mark types), a more effective way of differentiating marks emerge. For this purpose, a logistic regression analysis was used. When comparing trampling marks to cut marks made with simple flakes a six-step process produced the information shown in Table 1. The order of importance of variables, according to the Wald statistic and sigma values, are: mark shape, mark trajectory, trajectory of microstriations, location of microstriations, presence of microstriations and mark orientation. The model is valid (Hosmer & Lemeshow test shows sigma = .068) and classifies correctly 98.9% of both types of marks.

When comparing trampling marks to cut marks made with retouched flakes, a three-step process selects the predictor variables that determine the type of mark: presence of shoulder, mark trajectory and presence of flaking (Table 2). The model is valid (Hosmer & Lemeshow test gives sigma = .062) and classifies correctly 92.4% of both types of marks.

When comparing both types of cut marks, there is a more intense overlap than in previous pairwise comparisons, but a logistic regression analysis provides a solution (Table 3) in which two variables (presence of shoulder effect and presence of flaking on shoulder) classify correctly 68.7% of both types of marks, with better classification of marks created with retouched flakes (83.8%) than those made with simple flakes (55.7%) (Hosmer & Lemeshow test gives sigma = .17).

To sum up, when comparing the results obtained in the CATPCA analysis and the logistic regression analyses, it could be argued that cut marks made with simple flakes were overwhelmingly close-V/_/-shaped, whereas both trampling and cut marks made with retouched flakes were open-_/-shaped. Straight trajectories were the signature of cut marks and several trampling marks. From those marks that were straight and with internal microstriations, trampling could be further differentiated from cut marks made with retouched flakes by the presence of shoulder effects and extensive flaking on the edge of the shoulder, as well as by the location of microstriations both at the base and on walls in the cut marks. Continuous and straight microstriations inside marks also help differentiate between trampling marks and cut marks. The joint use of the these variables can be effectively used to discriminate among the three types of marks (Fig. 12).

Behrensmeyer et al. (1986) emphasized that the internal microstriations of cut marks and trampling marks are prone to disappear from modern bone and fossil bone surfaces. For this reason, if we exclude their effects on the statistical analysis shown, and compare trampling marks to cut marks made with simple flakes (where three variables involved in microstriations are relevant), a logistic regression (Table 4) shows that both types can be differentiated based on the shape of the groove and the trajectory of the mark. The model seems to be effective at correctly classifying 96.6% of both mark types and is valid (Hosmer & Lemeshow test shows sigma = .81).

For those marks that show overlapping signatures or whose interpretation using these variables is ambiguous, two variables can be discriminating that were not originally included in this analysis because they would be subjected to equifinality when comparing trampling marks and cut-marked bones subjected to trampling. Every single bone specimen subjected to trampling, irrespective of duration (10 s or 2 min), showed the typical microabrasion in the form of very shallow randomly distributed striae, which occupy various parts of the specimen. This microabrasion can only be properly identified with magnification (usually $>10\times$). In case of doubt, a bone specimen lacking this microabrasion would be indicative of absence of trampling. Likewise, 81% of conspicuous trampling marks showed the presence of (frequently shallower)

Table 4
Variables in the equation discriminating cut marks made with simple flakes and trampling marks, excluding the variables using microstriation data.

		B	SE	Wald	df	Sig	Exp (B)	95.0% CI for Exp (B)	
								Lower	Upper
Step 2	Trajectory	−3.999	.892	20.085	1	.000	.018	.003	.105
	shape	−8.670	1.414	37.579	1	.000	.000	.000	.003
	Constant	19.372	3.528	30.149	1	.000	258,966,185,602		

Variables entered on step 2: trajectory, shape.

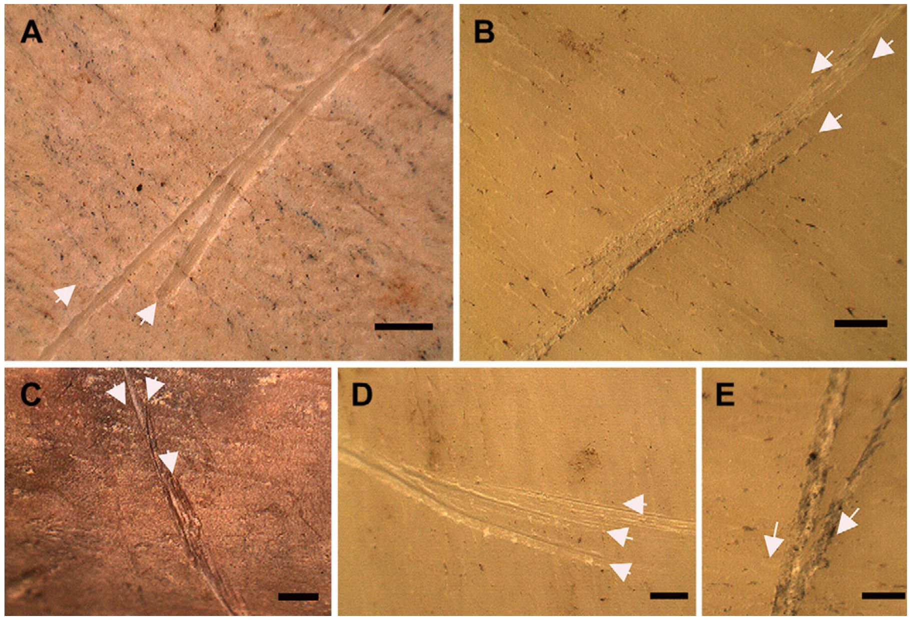

Fig. 13. Intersecting grooves caused in one single stroke by the irregular shape of the edge of retouched stone flakes. It can be double (A,E) or multiple (B,C,D).

striae running oblique to the axis of the trampling mark and either intercepting it or crossing it (as in Figs. 4 and 9). This can be seen in cut marks that were subjected to trampling, but was not documented in any of the marks experimentally reproduced for this study.

When comparing the different trampling experiments, neither time of exposure or sediment type affected the overall morphology of trampling marks. A factorial ANOVA analysis, derived through general linear models and using the variables that were important in the previous multivariate analyses, showed low F values (<3.5) and non-significant sigma values ($>.05$) for mark shape, mark trajectory, trajectory and location of microstriations, shoulder effect and flaking on shoulder when various time sets and sediment types are compared. The ANOVA analysis only showed a significant difference ($p = .026$) according to sediment type with respect to the presence of microstriations: fine-grained sediment produced a higher number of marks without observable microstriations under 40× than did the other sediment types.

Another contribution of the present work lies in the identification and comparative use of the microscopic and macroscopic criteria that distinguish cut marks created with retouched tools. Retouched flakes show a less straight outline of the edge than simple flakes, and for this reason the area of contact with the bone surface comprised by the width of the tool edge is wider, resulting in broader grooves. The irregular edge also accounts for the occurrence of striations parallel to the main groove (shoulder effect), which may be multiple, showing as a typically diagnostic characteristic that in some cases, their depth is similar to that of the main groove (Fig. 7). This contrasts with the much shallower (and frequently irregular) shoulder effect generally observable in trampling marks (Figs. 5 and 6).

Also, this irregular (sometimes serrated) profile of the edge creates a particular morphology in the resulting cut mark since the flake is commonly used in an up-and-down swinging motion, thus making some lateral part of the flake edge (produced by retouch) touch the surface before the remaining edge. This frequently produces one or more grooves that intersect with the main groove in the form of oblique grooves or a fork (Fig. 13). The difference between this situation and the oblique striations that intersect trampling marks caused by sediment abrasion lies in the depth of the former, which as in the case of shoulder effect are deeper than those documented in trampling marks, and are similar in depth to that of the main groove.

As a third diagnostic characteristic, flaking across an extensive portion of the shoulder can be documented either asymmetrically (on one shoulder) or symmetrically (on both shoulders) (Figs. 8 and 14). This has not been documented in any of the trampling marks created in our experiment. When this occurs in rare instances of cut marks made with simple flakes, it affects less than one-third of the shoulder, whereas it has repeatedly been observed on most of at least one of the shoulders of cut marks made with retouched flakes.

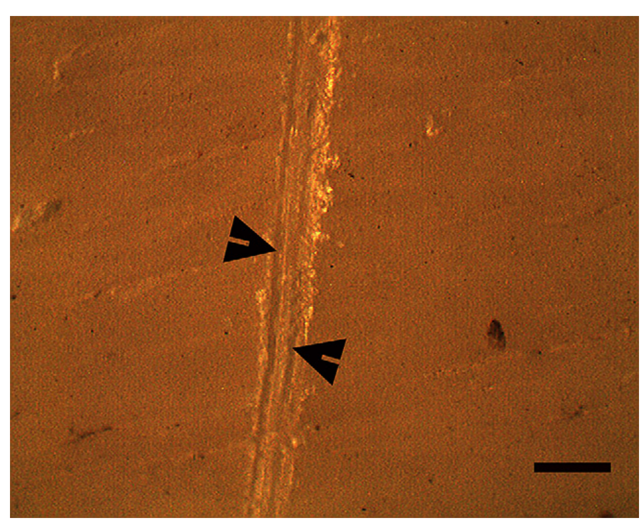

Fig. 14. Example of twin parallel grooves (arrows) created with a retouched flake, showing flaking on the shoulders that occurs asymmetrically, being more intensive on the right shoulder due to the inclination of the tool while performing the cut. Scale = 500 microns.

Table 5
Percentages of each categorical variable in the experimental sample reproducing trampling marks, cut marks made with simple flakes and cut marks created with retouched flakes.

	Trampling	Unretouched tool CM	Retouched tool CM
Groove trajectory			
Straight	75/251 (29.8)	230/246 (93.5)	102/105 (97.1)
Curvy	42/251 (16.7)	16/246 (6.5)	0/105 (0)
Sinuous	134/251 (53.4)	0/246 (0)	3/105 (2.9)
Barb			
Present	6/251 (2.4)	25/246 (10.2)	6/105 (5.7)
Absent	245/251 (97.6)	221/246 (89.8)	99/105 (94.3)
Mark orientation			
Parallel	25/251 (9.9)	1/246 (0.4)	0/105 (0)
Perpendicular	20/251 (8)	96/246 (39)	3/105 (2.9)
Oblique	206/251 (82.1)	149/246 (60.6)	102/105 (97.1)
Groove shape			
V	10/251 (4)	238/246 (96.7)	6/105 (5.7)
_/	241/251 (96)	8/246 (3.3)	99/105 (94.3)
Symmetry			
Symmetrical	226/251 (90)	212/246 (86.2)	42/105 (40)
Asymmetrical	25/251 (9.9)	34/246 (13.8)	63/105 (60)
Shoulder effect			
Present	15/251 (5.9)	81/246 (32.9)	78/105 (74.3)
Absent	236/251 (94.1)	165/246 (67.1)	27/105 (25.7)
Flaking on shoulder			
Present	7/251 (2.7)	36/246 (14.6)	54/105 (51.4)
Absent	244/251 (97.3)	210/246 (85.4)	51/105 (48.6)
Extent of flaking			
Long	2/251 (0.7)	0/246 (0)	12/105 (11.4)
Short	5/251 (1.9)	36/246 (14.6)	42/105 (40)
Absent	244/251 (97.2)	0/246 (0)	51/105 (48.6)
Overlapping striae			
Present	203/251 (80.3)	12/246 (12.9)	0/105 (0)
Absent	48/251 (19.7)	234/246 (95.1)	105/105 (100)
Internal microstriations			
Present	188/251 (75)	190/246 (77.2)	105/105 (100)
Absent	63/251 (25)	56/246 (22.8)	0/105 (0)
Microstriation trajectory			
Continuous	169/251 (67.3)	190/190 (100)	105/105 (100)
Discontinuous	82/251 (32.7)	0/190 (0)	0/105 (0)
Shape microstriation trajectory			
Straight	140/169 (82.8)	190/190 (100)	105/105 (100)
Irregular	29/169 (17.2)	0/190 (0)	0/105 (100)
Location of microstriations			
Walls	7/251 (2.8)	180/246 (73.2)	3/105 (2.9)
Bottom	219/251 (87.2)	0/246 (0)	93/105 (88.6)
Both	25/219 (10)	10/246 (4.1)	9/105 (8.6)
Microabrasion			
Absent	1/251 (0.4)	6/246 (2.4)	0/105 (0)
Present	250/251 (99.6)	240/246 (97.6)	105/105 (100)

Lastly, in several cut marks produced with retouched flakes a double groove can be documented, resulting from two differently-oriented sections of the active part of the retouched flake edge simultaneously scratching the bone surface (Fig. 14).

4. Discussion and conclusions

The present experimental study has shown that three features previously described as typical characteristics of trampling marks may be valid for bones subjected to intensive trampling but not for those exposed to brief trampling under 2 min: trampling marks do not have to show a rounded base and shoulder (see Figs. 4–6), they do not necessarily occur in greater abundance (as perceived by the naked eye) than cut marks, and they are not more randomly-oriented in a statistically significant way than cut marks. Trampling marks frequently showed an orientation oblique to the axis of the bone specimen, which was similarly documented among cut marks (although more frequently in the latter).

Bunn (1981) argued that cut marks were typically narrower and deeper than tooth marks. Shipman (1983) subsequently tried to refute this assertion by showing that cut marks could adopt a wide diversity of forms and some of them were as wide and shallow as tooth marks. Mark shape was claimed by Shipman (1983) to be a poor predictor of mark type. The present study supports Bunn's original interpretation by showing that cut marks made with simple flakes are essentially almost as deep or deeper than they are wide, and are clearly narrower than tooth mark scores (in the experience of the senior author; see also Domínguez-Rodrigo and Piqueras, 2003). Overall, butchery marks, especially those made with simple flakes, are deeper than trampling marks.

Behrensmeyer et al. (1986) also claimed that mark morphology and its internal features were not specifically diagnostic of cut marks. The present study shows that whereas this statement could be supported for specific overlapping trampling marks selected intentionally to show their similarities to butchery marks, the bulk of trampling marks can be differentiated from butchery cut marks (as also claimed by Olsen and Shipman, 1988) *if the discriminating variables discussed in this work are applied jointly*.

Olsen and Shipman (1988) produced several diagnostic criteria to identify trampling marks: number of marks per bone and their locations on the bone, their orientation, their morphology and depth, and their association with polish. Whereas we failed to identify polish in our trampled bones, probably because they were trampled for a maximum of 2 min in contrast with the 2-h trampling in Olsen and Shipman's (1988) experiment, we have encountered evidence to support some of their criteria: the morphology and depth of trampling marks on bone. Furthermore, Olsen and Shipman (1988: 543) noticed that

> "very fine, shallow striations were found on all of the long bones, except those placed in potting soil. The striations were widely and evenly distributed over the diaphyses. Diverse orientations of the striations caused them to intersect at various angles. Regardless of the sediment size, all of the striations were very fine and lacked the parallel lines within their main grooves commonly seen in butchering marks".

Our experiments exposing bones to as few as 10 s of trampling also produced the same type of evidence: fine striae in the form of microabrasion and striae intersecting at oblique angles, especially on the conspicuous marks. However, we argue that these two features can also be documented in cut-marked bones subjected to trampling post-depositionally.

Our statistical approach shows that more than 90% of marks were correctly classified as trampling marks or cut marks when considering a determined set of variables. See Table 5 for the frequency distribution of each variable in the tramping and butchery experiments. It is true that our experimental goal was to reproduce short-term trampling on bone, in contrast with previous experiments that have reproduced longer exposures to trampling. We do not know how many of the features uncovered in our experiments are applicable to assemblages trampled for longer periods. For an epistemologically correct application of our experiments as a referential framework, we argue that they can be applied as an analogue to archaeological and paleontological assemblages that have undergone non-intensive trampling. One way to interpret non-intensive trampling in prehistoric bone assemblages could be the absence of polish (which appears after 2 h of trampling), the absence of bone pitting and flaking which often occurs in such intensively-trampled bones and the loss of sharp edges along the breakage planes and on the shoulders of marks (Olsen and Shipman, 1988; this study). However, after having been cautious in the application of our experiments, it should be stressed that according to Olsen and Shipman's (1988) study, it seems that prolonged exposures to trampling further reduce (rather than increase) the similarities between trampling marks and butchery marks.

The results from the present study are best applicable in cases of low-intensity trampling. Behrensmeyer et al. (1986) pointed out that the survival of internal microstriations can be rare. Cut marks experimentally created and subjected to intensive trampling lost their internal microstriations and also underwent transformation of their shoulders, with appearance of flaking (see Figs. 2 and 3 in Behrensmeyer et al., 1986). If this is taken into consideration, then some of the diagnostic features that distinguish mark types would be subjected to equifinality. In such circumstances, the differentiation with greatest heuristic value would be between trampling marks and cut marks made with simple flakes. Mark trajectory and groove section shape would be the most reliable variables.

One of the novel approaches of our study was the use of retouched flakes to compare the resulting marks with cut marks created with simple flakes and trampling marks. The irregular edges of retouched flakes created broad marks with parallel striae running along the shoulder, and these flakes modified the edge of the shoulder itself with extensive flaking. The various crested points along the retouched edge inserted themselves into the bone surface, frequently producing multiple grooves that intersected with one another in the form of forks and double grooves.

The resulting diagnosis on butchery marks and trampling marks given here has the advantage of being functionally applicable to the study of complete bone assemblages, since all the marks can be scrutinized with low magnification lenses. It is hoped that such a referential framework will provide greater resolution in the understanding of bone assemblages subjected to some degree of trampling, such as those frequently retrieved in sandy sedimentary contexts, and of those assemblages in which cut marks are either underestimated by conservative approaches or overestimated by careless identification of marks.

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