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Surface Modification on Bone: Trampling versus Butchery

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Previous researchers have reported difficulties in distinguishing between surface marks on bone formed by sedimentary abrasion and those inflicted while butchering. Trampling by large ungulates and humans has been credited with producing pseudo-cut marks: natural alterations to the bone that mimic cultural ones. The purposes of this research are: (1) to re-examine trampling as a taphonomic process, and (2) to suggest criteria useful for distinguishing sedimentary abrasion, including trampling, from butchery. Macroscopic and microscopic comparison of experimentally trampled bones and those which have had soft tissue removed with a flint tool demonstrate significant differences between the surface modifications produced by the two processes.

Keywords: TRAMPLING, CUT MARKS, BUTCHERY, STRIATIONS, TAPHONOMY, SCANNING ELECTRON MICROSCOPY.

Introduction

A number of papers have been published on modifications to bone produced by trampling by humans and large ungulates. The research that has been done to further the understanding of trampling as a taphonomic process may be divided into four major categories.

(1) Examination of bone from palaeontological (Myers *et al.*, 1980; Agenbroad, 1984; Fiorillo, 1984; Behrensmeyer, 1984; Behrensmeyer *et al.*, 1986) or possibly archaeological (Oliver, 1984, 1986) sites in which conditions suggest that trampling was a significant cause of damage.

(2) Observation of bones altered by modern trampling by indigenous people (Brain, 1967; Gifford, 1977; Gifford & Behrensmeyer, 1977) or herds of animals (Brain, 1967; Haynes, 1986);

(3) Experimental replication of trampling of bones by humans (Villa & Courtin, 1983; Gifford-Gonzalez *et al.*, 1985; Behrensmeyer *et al.*, 1986; M. H. Newcomer & S. L. Olsen, in preparation) or herds of animals (Fiorillo, 1984).

(4) Collection of modern bones from the ground surface where conditions suggest that trampling was a major source of damage, but where actual observation of the activity is absent (Behrensmeyer, 1984; Andrews & Cook, 1985).

All of these methods have certain intrinsic disadvantages and limitations which must be recognized in order to temper interpretations of bone modification as trampling marks.

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Studies in categories (1) and (4) 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*. Studies in categories (2) and (3) are less subject to misinterpretation since trampling is actually observed, but other minor factors (known or unknown) may also be involved in bone modification. The advantage of studies in category (2) is that the trampling occurs in a natural environment. The disadvantage is that other taphonomic or cultural processes are likely to play a role in the modification of bone that may be either significant or trivial. Because direct observation of the taphonomic history of the bones is involved, it is likely that these factors can be fairly accurately identified. The advantage of experimental trampling (3) is that, if properly controlled, it may essentially eliminate all other taphonomic processes. The chief problem with experimental trampling is that unnatural conditions may introduce other factors or create trampling marks on the bone which do not closely replicate those produced under normal conditions. In addition, many researchers have used old, weathered bone picked up from the ground for their experiments. In some cases, the bone surfaces have not been replicated before experimental trampling, making it impossible to document the differences between surface marks created prior to the experiment and those inflicted during the experiment. At this stage in the continuing research on trampling, it is beneficial to bring together and summarize the observations that have been made, and to attempt to enhance our definitions of different kinds of surface modifications on bone that are associated with trampling. A significant problem is the possible confusion between surficial traces on bone produced by trampling and those made during butchering (Fiorillo, 1984; Oliver, 1984, 1986; Behrensmeyer *et al.*, 1986). It is also not established that the marks left by trampling can be reliably distinguished from breakage and sedimentary abrasion caused by other forms of pedoturbation, such as frost-heaving, gelifluction, argilliturbation, movement along fault lines, solifluction, soil creep, subsidence in limestone karst topography, roof fall in caves and rock shelters, tillage, and so forth (see Wood & Johnson, 1978). It is, therefore, necessary to establish criteria for segregating trampling from humanly inflicted cut marks, and if possible, from other taphonomic processes which move, break, abrade and otherwise modify bone.

Trampling as a Taphonomic Process

When bones or other materials are trampled, whether by humans or quadrupedal animals, the archaeological record is altered. These changes can be summarized as *spatial* (horizontal and vertical movement or rotation) and *physical* (breakage and surface modification). Horizontal movement usually takes place while the bone is lying on the surface of the ground rather than when it is buried. Scuffing or kicking can lead to movement of individual objects over great distances, e.g. 85 cm in one experiment (Villa & Courtin, 1983: 277). Horizontal movement seems to be related to the compaction of the soil. A hard substrate enables bones to stay on the surface longer, which increases the probability of horizontal movement. In a loose soil, the objects are readily submerged beneath the surface and are, therefore, less susceptible to kicking (M. H. Newcomer & S. L. Olsen, in preparation). Villa & Courtin (1983) found no correlation between weight of the object and the extent of horizontal displacement.

Vertical movement is more consistently observed in experimental trampling than horizontal movement, but it is also highly variable. Movement is generally downward because pressure from the foot pushes the solid object into the soft substrate. Notable amounts of upward movement may occur in very loose sediments, such as dry sand, when a foot placed immediately adjacent to the object sinks deeply into the substrate and displaces the object and adjacent sediments both laterally and upwardly. For example, Stockton (1973) reported that over half of the pieces of glass he placed in loose, dry sand were moved upward during trampling. Upward movement has also been reported simply through lateral movement over an irregular ground surface (Villa & Courtin, 1983: 273).

The extent of downward movement depends on a variety of factors, including the intensity of trampling, the degree of compaction of the sediments, extent to which the objects are covered by soil, and the weight and dimensions of the object (Villa & Courtin, 1983: 275). Presumably, the force inflicted by the foot also has an important bearing on the amount of downward movement of the trampled object. The content and texture of the soil makes a significant difference as well, since Gifford (1977; 240–1) found rapid burial in soft, sandy soil, but Newcomer & Olsen (in preparation) found very little downward migration in deposits combining loose silt and limestone gravel. In the latter case, the gravel apparently acted much like a pavement, preventing further compaction and downward migration of the objects.

Sorting of objects by size and surface area has been observed by Gifford at the modern Dassanetch site 20 after just four days of trampling (Gifford, 1977: 183). Fish vertebrae and ribs, small crocodile scutes and other small elements became deeply submerged in the soil, while bones with a larger surface area, such as terrapin shells, fish skulls and crocodile limb bones, stayed on the surface.

Orientation and declination may change through trampling, while some pieces may also become inverted or rotate. During experimental trampling, elements have been observed to submerge and resurface (Villa & Courtin, 1983: 275; Gifford-Gonzalez *et al.*, 1985: 809; M. H. Newcomer & S. L. Olsen, in preparation; our observations), especially when a long bone is stepped on at one end, lifting the opposite end out of the soil. Subsequent trampling of uplifted ends of bones may result in burial of such bones in a nearly vertical position (Hill & Walker, 1972: 405). Skulls and other large bones lying in the path of animals are often avoided as any large object would be (Behrensmeyer & Dechant Boaz, 1980; 87; Shipman, 1981: 119).

The result of movement of archaeological bone by trampling may be extremely significant. Elements from articulated skeletons may become disarranged so they no longer appear to be from one individual. Primary associations between bones and other cultural remains and features may be disrupted through trampling beyond the point where reconstruction of the original associations is possible. The most serious and frequently cited concern about trampling disturbance is the mixing of non-contemporaneous cultural layers (Villa & Courtin, 1983).

Breakage has also been observed after bones have been trampled, particularly if the material has been exposed on the surface long enough to become weathered and cracked (Villa & Courtin, 1983; Andrews & Cook, 1985). Fresh bone that is experimentally trampled is less likely to break (M. H. Newcomer & S. L. Olsen, in preparation). Elements with thin cortical bone are more susceptible to breakage through trampling than more solid elements. For example, Andrews & Cook (1985) reported the breakage of a mandible, a scapula, ribs, vertebrae and a pelvis. Bones, such as the humerus or tibia, which have a predominantly spiral orientation of collagen fibres may fracture spirally when trampled even after weathering cracks have developed (see Hill, 1976; Shipman, 1981). Since breakage from trampling tends to occur in the weakest parts of the bone, as it would in most natural circumstances, there does not appear to be anything particularly diagnostic about the type or patterning of breaks created by this process.

An area of great concern with regard to archaeological bone is the possible mimicking of butchery marks by trampling (Fiorillo, 1985; Oliver, 1984, 1986; Behrensmeyer *et al.*, 1986; Haynes, 1986). It is important, then, to find distinguishing characteristics, either in terms of groove morphology, patterning and distribution of traces, or associations with other types of surface modification (like polishing) in order to separate marks inflicted by trampling from cut marks. To further explore surficial alterations created by trampling we conducted a set of experiments using fresh bone, described below.

Palaeontologists and archaeologists are beginning to diagnose marks of unknown origin as trampling marks, thus tacitly implying that such surface traces bear characteristics that reliably distinguish them from abrasive marks created by other forms of pedoturbation. In fact, these other types of pedoturbation are only rarely considered as alternative causes of the sedimentary abrasion. We suggest that it would be an extremely rare circumstance in which all causes of abrasion other than trampling could be eliminated. Only in unusual cases of prehistoric bone deposits can trampling be confidently demonstrated to have occurred at all, and even then other factors, such as roof or wall collapse, may be involved (Oliver, 1984, 1986; Agenbroad, 1984). It is perhaps more cautious and accurate, then, when discussing archaeological material, to refer to such surface modifications as sedimentary abrasion and list possible causes rather than labelling the traces as trampling marks.

Sedimentary abrasion is created by pressure on or within deposits that causes sediments to slide across the bone or vice versa. This may be distinguished from erosional wear, caused by air- or water-borne particles impinging on the bone surface. The appearance of abrasion is usually different enough from erosional wear to allow the two to be segregated (Brain, 1967). Since erosional wear does not usually leave striations that mimic cut marks and is not caused by trampling, descriptions of surface modification due to aeolian or fluvial action will not be attempted here.

Our work builds on that of previous researchers who have conducted experiments or recorded observations of trampling and how it modifies bones surfaces. Their work is only briefly summarized below; readers are referred to the primary publications for more detail.

To recreate fine striations on bone from the Miocene Hazard Homestead Quarry in Nebraska, Fiorillo (1984) subjected 90 bones of *Bos taurus* and *Sus scrofa* to trampling by cattle for five weeks. The soil around a salt lick where the cattle congregated and where the bones were deposited was described as "... hard, sandy, and dry ..." (Fiorillo, 1984: 47). The bones were examined prior to placement in the soil and were found to have weathering cracks and carnivore tooth marks, but no fine striations. Following the experiment, we were permitted to make replicas of the surfaces of two of the bones for scanning electron microscope (SEM) examination.

Behrensmeyer *et al.* (1986) described an experiment in which naturally cleaned bones were subjected to 3 minutes of trampling on a river bank by an investigator wearing soft-soled shoes. Some bones were intentionally cut with a stone tool and replicated prior to and after trampling. We were permitted to take our own replicas of these bones for comparison with bones from our experiments. The conclusion drawn from their experiment was that "... marks made by sand grains during a brief period of trampling are similar, at magnifications up to 400 ×, to marks made by a stone tool." (p. 770).

Andrews & Cook (1985) examined cow bones which had been exposed for 7·5 years on a limestone shelf located in a cattle path in Somerset, England. The primary taphonomic processes leading to bone surface modification, inferred from the known setting and extant environmental conditions, were trampling by cattle, gravitational movement and root-etching. Bone surfaces were studied with SEM and various features described in detail. This case, in which heavy-bodied, hooved animals walked over bones on a stony substrate for a period of years, may represent one of the most extreme forms of trampling known from modern observations. Their results demonstrate the possible range of

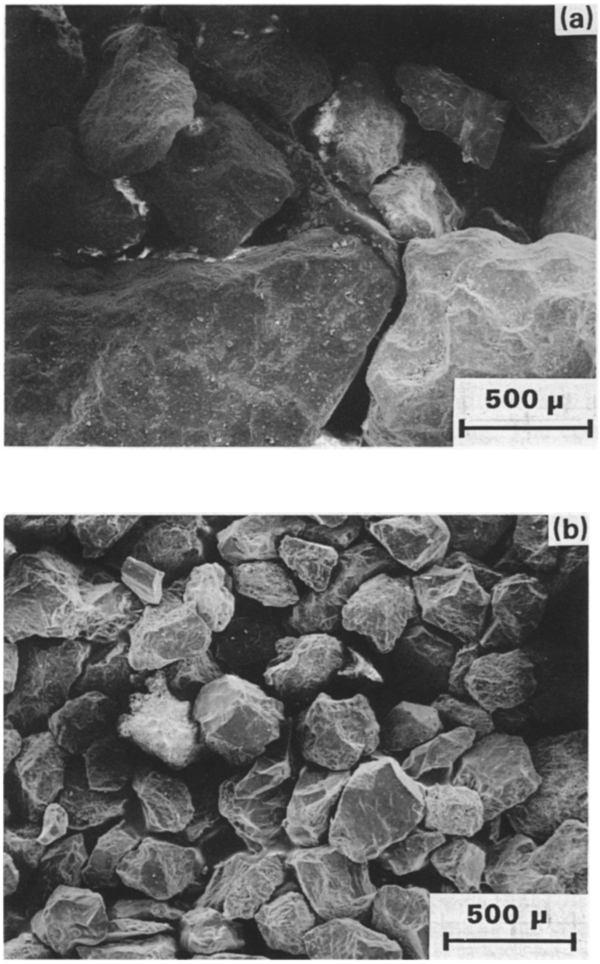


Figure 1. (a) Coarse sand grains from trampling experiment conducted in the laboratory. (b) Fine sand grains from trampling experiment conducted in the laboratory.

variation in surface marks caused by trampling. They characterize the resultant linear grooves as "... numerous, generally superficial, closely spaced, intersecting and of variable curvature, length and breadth." (Andrews & Cook, 1985: 681).

Experimental Trampling

In order to recreate trampling of bone by human or soft-footed animals, four plastic trays (each 43 × 30 × 8 cm) were filled with different grades of sediments. The first held pea gravel, the second coarse sand [Figure 1(a)], the third fine sand [Figure 1(b)] and the fourth potting soil. The pea gravel was subangular to well-rounded and ranged in size from about 5–15 mm in maximum diameter; the coarse sand was subangular and ranged from about 0·5–2 mm; and the fine sand was subangular and ranged in size from about 0·1–0·5 mm. Fresh bones of *B. taurus* and *Ovis aries* (Table 1) were placed in the trays with adequate space around each element to allow movement in all directions. The bones, obtained

Table 1. Bones used in trampling experiment

Sediments	Specimen #	Species	Element	Polish	Linear grooves	Nicks
Pea gravel	5	*Ovis aries*	Metacarpal	+	+	−
	7	*Bos taurus*	Radius	+	+	−
	15	*Ovis aries*	Unciform	−	−	−
	16	*Ovis aries*	Magnum	−	−	−
	21	*Ovis aries*	Unciform	−	−	−
	26	*Ovis aries*	Scaphoid	−	−	−
	29	*Ovis aries*	Lunate	−	−	−
	32	*Ovis aries*	Cuneiform	−	−	−
Coarse sand	1	*Ovis aries*	Metacarpal	+	+	−
	6	*Bos taurus*	Humerus	+	+	−
	12	*Bos taurus*	Scaphoid	−	−	−
	17	*Ovis aries*	Magnum	−	−	−
	22	*Ovis aries*	Unciform	−	−	−
	27	*Ovis aries*	Scaphoid	−	−	−
	30	*Ovis aries*	Lunate	−	−	−
	33	*Ovis aries*	Cuneiform	−	−	−
Fine sand	4	*Ovis aries*	Metacarpal	+	+	−
	9	*Bos taurus*	Femur	+	+	−
	14	*Bos taurus*	Magnum	−	−	−
	18	*Ovis aries*	Magnum	−	−	−
	23	*Ovis aries*	Unciform	−	−	−
	28	*Ovis aries*	Scaphoid	−	−	−
	31	*Ovis aries*	Lunate	−	−	−
	34	*Ovis aries*	Cuneiform	−	−	−
Potting soil with flint	3	*Ovis aries*	Metacarpal	−	+	+
	8	*Bos taurus*	Ulna	−	+	+
	11	*Bos taurus*	Cuneiform	−	−	−
	19	*Ovis aries*	Magnum	−	−	−
	20	*Ovis aries*	Magnum	−	−	−
	24	*Ovis aries*	Unciform	−	−	−
	25	*Ovis aries*	Unciform	−	−	−
	35	*Ovis aries*	Pisiform	−	−	−
	36	*Ovis aries*	Pisiform	−	−	−

from a butcher, were first boiled gently to remove the soft tissue. The remaining hyaline cartilage, periosteum remnants and any adhering tendons or ligaments were taken off using fingernails or a flexible plastic spatula in order to ensure that no scratches were created on the bone. When clean and dry, each bone was inspected with an optical microscope at 50 × to locate any surface alterations. The long bones exhibited some butchering marks, including both shallow scrapes and quite deep cuts made with modern steel cleavers and knives. These were illustrated on line drawings, photographed and replicated with silicone rubber and epoxy resin (after Rose, 1983) prior to any further treatment of the bones.

In the experiment, the bones in each tray were walked on by barefoot people for a cumulative time of 2 h per tray. Participants were barefoot to avoid the possibility that the soles of the shoes themselves would create marks or would hold sediments in a fixed position and alter the form of abrasion. The duration of this experiment exceeded that of the previous trampling experiments by a wide margin in an attempt to replicate repeated trampling over a period of months under natural conditions. Efforts were made to step directly on the larger bones, as well as the surrounding sediments, despite the fact that this was often uncomfortable or even painful to the participants. In a natural setting, humans and other animals would probably avoid stepping on large or irregularly shaped bones if possible.

Upon completion, the bones were gently removed from the sediments, washed and dried. Each element was again inspected with a stereomicroscope and areas of the surface were replicated for study with an ETEC Omniscan scanning electron microscope.

After documenting that no striations, or linear grooves, were created by trampling in plain potting soil, this set of bones was placed in the soil with flakes of flint from Brandon, England. The 23 flakes ranged in size from 11–55 mm in maximum dimension. In consideration for their safety, the participants in this phase of the experiment wore soft-soled rubber thongs during trampling. In this case, the bones were trampled with flint flakes for one additional hour before they were examined with the optical microscope and replicated for SEM analysis.

For comparison, experimental butchery marks were produced on a fresh sheep metacarpal prepared identically to those subjected to trampling. The condition of the bone surface was documented and replicated prior to the experiment as described above. The bone was sliced transversely with a sharp flint flake held perpendicular to the bone surface and drawn parallel to the long axis of the flake. In another area of the bone a flint burin was pushed firmly against the bone in a scraping motion perpendicular to the tool's edge, removing fine shavings of bone from the surface. On the reverse side, the bone was abraded with fine sandstone. The three areas of modification were then replicated for examination with the SEM.

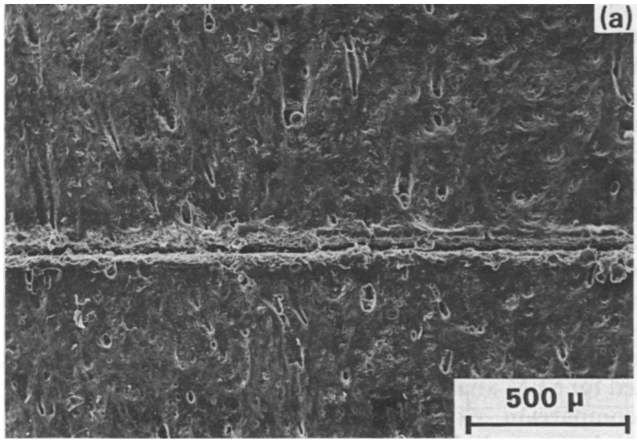
The experimental cut marks resemble those made when butchering an animal with stone tools and those frequently seen on prehistoric faunal remains from archaeological sites. The marks are deep, narrow, V-shaped grooves containing fine, parallel striations along their walls [Figure 2(a), (b)].

Scraping with a burin produced a 2 mm wide facet with fine parallel striations running the length of the diaphysis of the bone (Figure 3). The micro-cutting of the bone by scraping can remove sufficient material to eliminate many of the natural contours, rugosities and outer surface structures of the bone. Features which are commonly found on scraped surfaces are chatter marks, or low, undulating ripples that run perpendicular to the striations (Newcomer, 1974: 149). These ridges, which make the striations wavy in appearance, are not associated with sedimentary abrasion. It is possible to scrape bone lightly during butchery without creating chatter marks, but the striations alone are usually distinguishable from those made by individual grains of sediment during trampling.

Figure 4 shows the microscopic traces formed when a flat piece of sandstone was rubbed over the bone, as was sometimes done by prehistoric people to shape bone artifacts during manufacture. The resulting surface alterations consist of many sets of closely packed, overlapping striations of fairly uniform depth, width and spacing. Deliberate abrading of this type removes considerable surface material, forming flat facets that alter the bone's natural contours. The striations are not wavy and lack chatter marks. Since abrading is usually repeated in one area several times and may be multidirectional, sets of striae may cross and intersect, even forming zigzagged patterns at times.

Additional Experimental Data

In order to stimulate human trampling of deposits in the Upper Palaeolithic rock shelter of Klithi, northwest Greece, a 1 m square, 20 cm deep trench was filled with sterile silt and limestone scree derived from the cave (M. H. Newcomer & S. L. Olsen, in preparation). Two artificial cultural layers, consisting of flint flakes and sheep and fish bones, were laid out over the square, separated vertically from each other by an intervening layer of 5 cm of



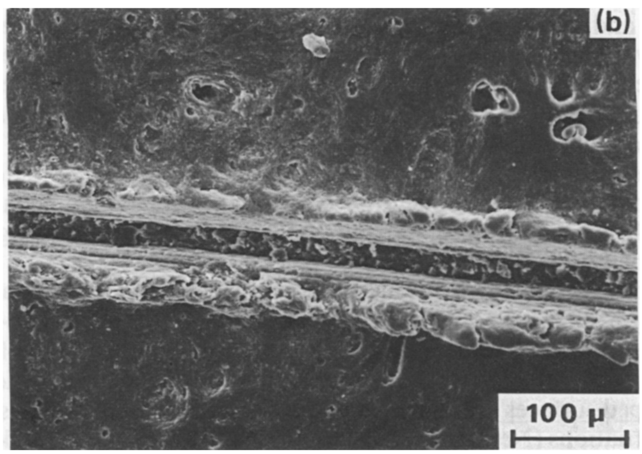
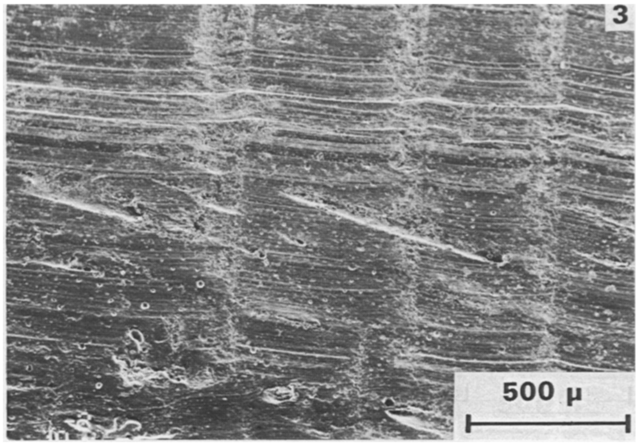


Figure 2. (a) Experimental cut mark on an *Ovis* metacarpal, made with an unretouched flint flake. (b) Close-up of the same cut mark. Note that it has steep sides with fine parallel striations running along its walls.

sterile soil and scree. Some of the long bones were broken with a hammerstone before being deposited. Drawings were made of the individual pieces of flint and bone, and breakage and butchering marks were recorded on these drawings. The position of each object was measured in three dimensions after being placed in the test square and again after the trampling experiment was completed. The square was casually crossed by approximately 25 excavators, wearing soft-soled shoes or sandals, several times a day for a week. The sheep bones collected after the experiment were examined with a stereomicroscope at 50 × and surface alterations were replicated for SEM study.

Results

Our observations of the modifications on trampled bone agreed in general with those made by Brain (1967, 1981). First, experimental trampling in the laboratory created a polish on the surfaces of all of the long bones except those in plain potting soil (Figure 6).



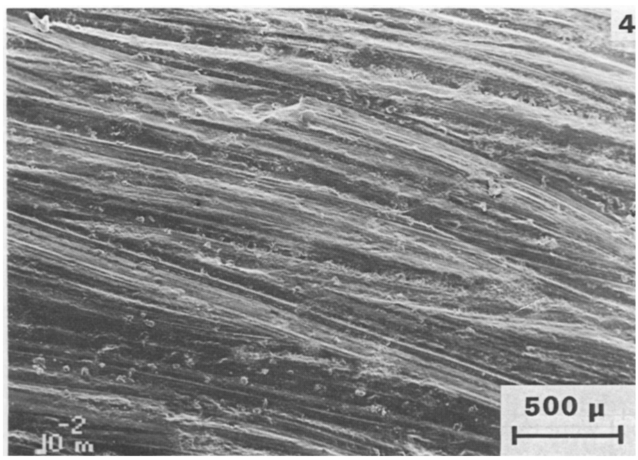


Figure 3. Modern bone (*Ovis* metacarpal) scraped with a flint burin. Scraping striations are shown as horizontal lines; chatter marks appear as vertical ridges.

Figure 4. Modern bone (*Ovis* metacarpal) abraded with a flat piece of sandstone using repeated bidirectional motions.

The cattle and sheep long bones trampled in pea gravel bore the highest polish, followed by those in coarse sand, and finally the fine sand.

Second, very fine, shallow striations were found on all of the long bones, except those placed in potting soil [Figures 5–7(b)]. 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 (Potts & Shipman, 1981).

Third, the carpals and tarsals that were placed in the trays alongside the long bones demonstrated very little change in their surfaces. This is best explained by the facts that the smaller bones were quickly covered with sediments and that they moved considerably less

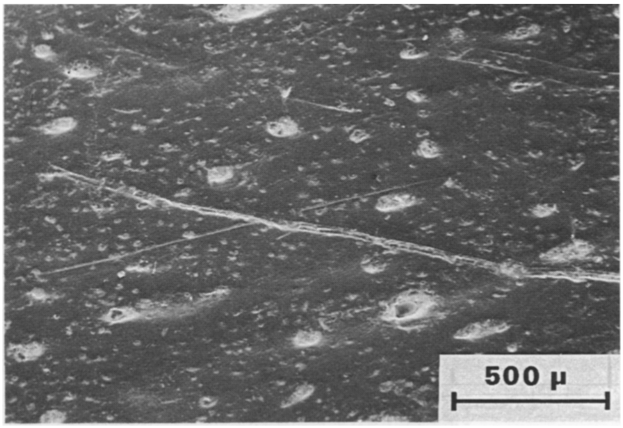


Figure 5. Modern *Bos* radius trampled by humans in pea gravel for 2 h. Note the variability in groove sizes.

than the long bones. Conversely, the long bones resurfaced repeatedly, rotated and shifted position frequently.

Somewhat different results were obtained when bones were placed in potting soil with flint flakes. The *Bos* ulna and *Ovis* metacarpal used in this experiment acquired a few short marks, or nicks, but no polish. Scanning electron microscopy examination of these marks demonstrated that they contained features similar to chop marks or scrapes rather than to slicing marks made during butchery. In some cases, debris was pushed up on either side in the same manner as it is around broad, V-shaped chop marks [Figure 8(a), (b)]. The major difference between the trampling marks and those produced with a chopper was the depth of the groove. Trampling produced much shallower marks on the fresh bone than chopping does. Additionally, the action of chopping is usually repeated numerous times in one concentrated area, but the trampling marks were, in this case, all solitary nicks.

The trampling marks that were somewhat similar to scraping marks made with a stone tool were expressed as shallow bands of parallel grooves, lightly incised into the bone's surface. All of these marks were quite short (less than 3 mm) and were distributed sporadically along the diaphyses of the ulna and metacarpal. Thus, these marks differed in several important aspects from scraping marks produced with a stone tool: (1) they were shorter than most true scraping marks; (2) they were not located in anatomically meaningful areas; (3) they removed very little of the surface of the bone, so that no facet was formed; and (4) they lacked chatter marks.

Considering the fact that the bones came into contact with the flint flakes frequently and that crushing of the flakes' edges was audible on numerous occasions, there were remarkably few alterations to the bone surfaces. In order for trampling marks that closely resemble cut marks made during butchering to be produced, a sharp stone flake would have to contact the bone at an angle roughly perpendicular to its surface and then slide across the bone, maintaining its relative position. In butchering, the asperities on the stone tool's edge produce the parallel striations within the groove that characterize slicing marks. While this could happen on rare occasions with trampling, our intensive experiments failed to produce any marks of sufficient depth and of proper morphology to be mistaken for normal butchery cuts after careful inspection. In most natural settings, the stone flakes would be expected to be lying in approximately the same plane as the bones prior to trampling. When stepped on, the flakes may be pushed against the bone, but not

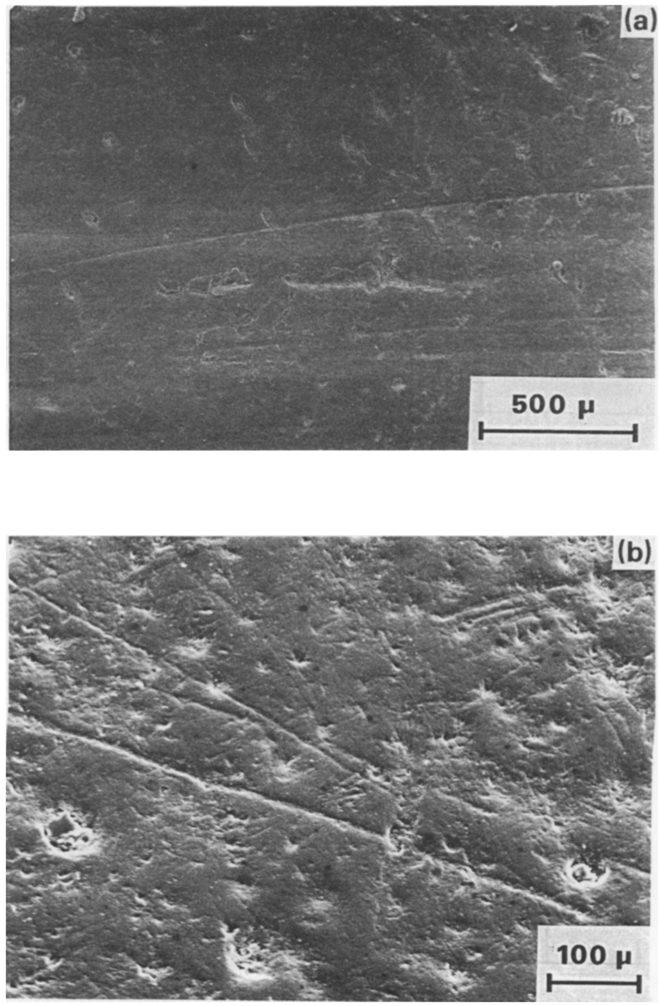


Figure 6. (a) Modern *Bos* humerus trampled by humans in coarse sand for 2 h. Note the abundant fine striations. (b) Close-up of the same surface showing striations of various widths and orientations.

usually in a position perpendicular to it. Even if the edge makes initial contact in the correct position, it is likely that the brittle flint will shatter under the force of trampling. To create a cut mark on the bone's surface, a flake should be relatively thin and sharp. This is why butchering requires a light touch to prevent crushing and dulling the tool's edge by contact with the bone, precisely what happens when a heavy foot presses the edge of the flint into the bone.

The experimental trampling of bones by humans conducted at the site of Klithi, in northwest Greece, also failed to produce mimics of cut marks. Despite their juxtaposition in the soil with pieces of limestone and sharp flint flakes, the bones acquired very few striations visible to the unaided eye. None of these was likely to be mistaken for a cut mark, since they were all very fine and shallow scratches without definable patterns of orientation. Some were similar to intentionally made scraping marks [Figure 9(a)] in that

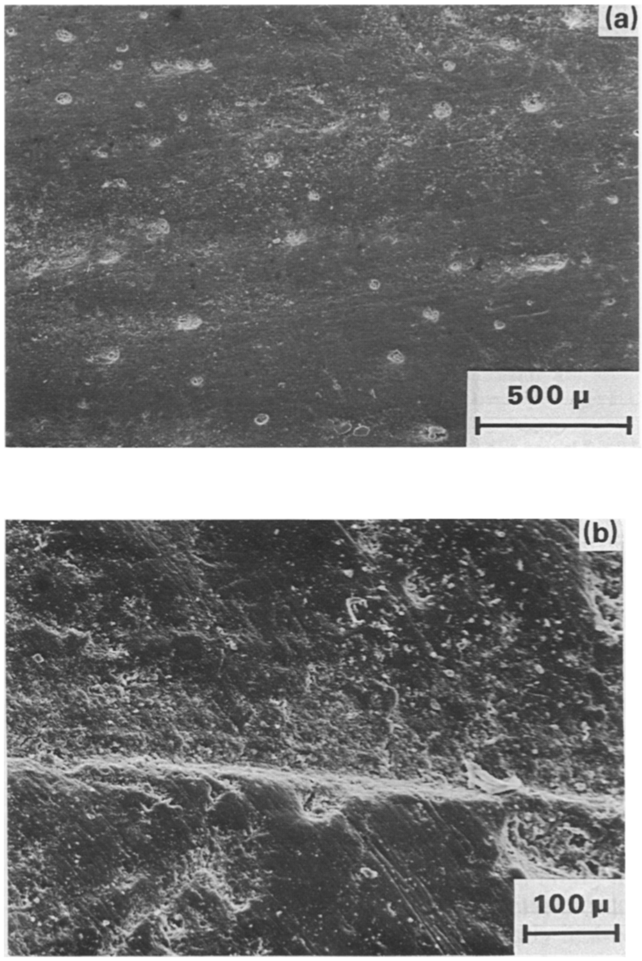


Figure 7. (a) Modern *Bos* femur trampled by humans in fine sand for 2 h. Note the very fine striations. (b) Close-up of the same surface showing details of one striation.

they consisted of a broad, flat band of fine parallel striations. However, these all lacked the chatter marks commonly associated with scraping performed during artifact manufacture (Figure 3). The trampling marks removed very little of the original bone surface in comparison to scraping with a flint tool, which can substantially alter the contours of a bone by planing off a large portion.

The two bones from Fiorillo's trampling experiment using cattle were heavily marred by striations. The vast quantity of visible marks contrasts sharply with those produced with human trampling of fresh bone. It is difficult to determine if the difference is due to the fact that large, heavy animals were trampling the bone, or because the bone was weathered and therefore less resistant to damage. The striations on these bones were widespread over the diaphyses of the long bones (Fiorillo, 1984) and showed no definite orientation or particular placement relative to anatomical features such as articular ends or areas of muscle attachment. Those marks we were able to examine were generally fine,

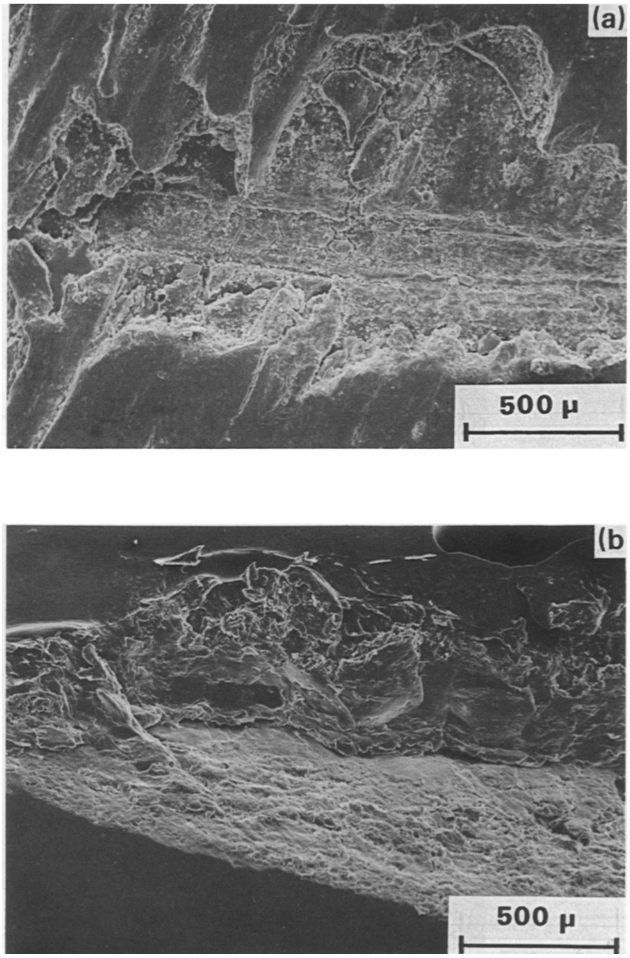
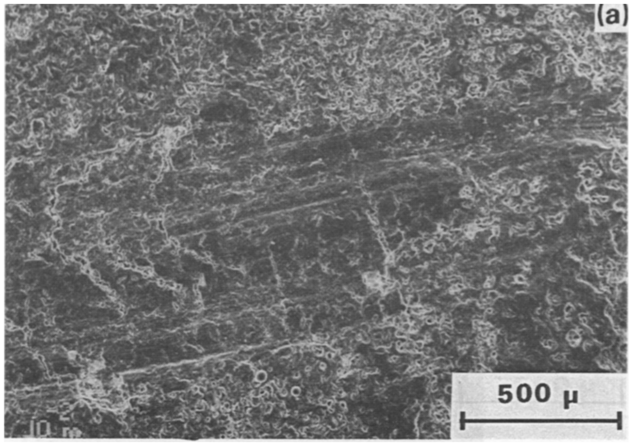


Figure 8. (a) Modern *Ovis* metacarpal trampled by humans in potting soil containing fresh flint flakes. The nick created by the flint superficially resembles a chop mark. (b) Experimental chop mark made by striking an *Ovis* humerus with an obsidian chopper. A deep, V-shaped mark with transverse striations running down into the base was produced by a single blow.

shallow and lacking in internal parallel lines. Broad scratched areas resembling scraping marks, like those seen on the Klithi material, were also present [Figure 9(b)].

Replicas were also taken of eight bones from the Miocene material collected from Hazard Homestead Quarry by Fiorillo (1984). These fossils also have abundant striations over their surfaces. Fiorillo (1984) has suggested that features on these bones were similar to those produced by experimental trampling. We concur that the marks have features commonly attributed to natural sedimentary abrasion. We did not observe fine, parallel lines within striations and the individual grooves were very fine, even in comparison to cut marks made with thin, unretouched flint flakes. There was no definite preferred orientation to the placement of the striations [Figure 10(a), (b)] and they were distributed widely on the diaphyses of long bones.



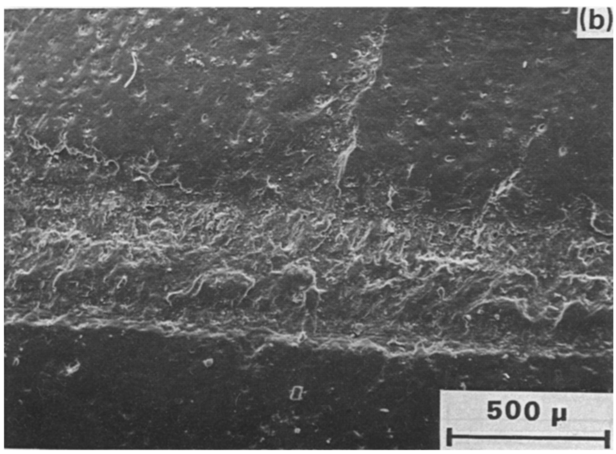


Figure 9. (a) Shallow set of sweeping striations which superficially resemble scraping marks, produced when fresh *Ovis* bone was trampled in silt with limestone scree at Klithi, northwest Greece. (b) Shallow striations made when cattle trampled a *Bos* radius in Fiorillo's experiment.

The bones from experiments by Behrensmeyer *et al.* (1986) showed similar modification of the surfaces with broad, shallow bands of parallel striations (resembling scraping) and areas criss-crossed by abundant superficial incisions. The only case in which natural circumstances appear to have produced a number of marks which resemble slicing marks in gross and microscopic detail was reported by Oliver (1984, 1986) from the site of Shield Trap Cave, Montana. Oliver's reconstruction of the site's formation involves rock falls in which broken limestone cobbles and boulders have produced sharp-edged pseudo-tools. He believes this was then followed by trampling of the bones of previous victims by animals that temporarily survived the fall, rubbing the sharp stones, which were fixed in the matrix, against bone. This sequence of events, if accurately reconstructed, could possibly produce cut mark mimics. Oliver (1986: 244) remarked that mimics of scraping marks were more common than those of slicing marks.

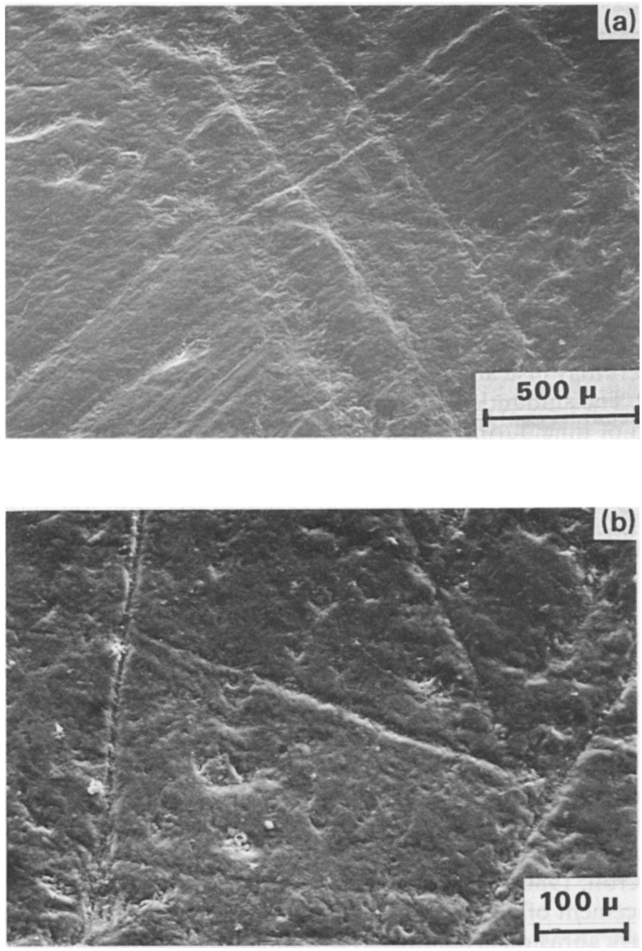


Figure 10. (a) Surface of a camelid (?) rib of Miocene age from the Hazard Homestead Quarry, exhibiting striations from sedimentary abrasion. (b) Another area of the same element at a higher magnification.

Conclusions

Our laboratory and field experiments using humans to trample bone, and those performed by Fiorillo and Behrensmeyer and her colleagues, all produced similar results. Regardless of the sediments used (pea gravel, coarse and fine sand, silt with limestone and potting soil with flint flakes), none of the marks matched cut marks in all details. Polish developed on bones intensively trampled for 2 h in abrasive sediments, and shallow, randomly oriented striations were produced in all cases except where potting soil alone was used. We conclude that, in assessing whether features on archaeological bone were created by cultural or natural phenomena, it is important to look at a variety of criteria. In addition to the sedimentary context of the bone assemblage and the angularity and sharpness of larger particles, pebbles or cobbles, we suggest the following set of features be examined: frequency of modified bone in the assemblage; number of marks per bone and their locations on the bone; their orientation; their morphology and depth, and their association with polish.

Frequency
Sedimentary abrasion tends to be indiscriminate in terms of the elements on which it occurs and is found more or less throughout the affected assemblage. Butchery, on the other hand, tends to be more localized on particular elements and on certain parts of elements. As a result, the frequencies of the natural striations tend to be higher than butchery marks. Butchery marks rarely occur on more than 20% of the bone fragments collected from a site, with 1–10% being more typical (Bunn, 1982: 210). Under the right conditions, sedimentary abrasion may affect most of the faunal material from a site.

Number per bone
The number of striations on the surface of an individual bone exposed to sedimentary abrasion of any kind is often so high that it is difficult to count individual marks. Researchers may instead prefer to discuss the proportion of the bone surface covered with striations. The amount of surface area affected and the density of the marks are related to the length of time during which the bone was abraded and the intensity of the abrasive process. Particle angularity may also be a factor, with more angular grains producing greater damage than predominantly rounded grains. With butchery marks, there are usually only a few distinct striations which may be readily counted. The only important exceptions are when meat is removed by filleting, when tendons are stripped from the bone for use as sinew thread (Olsen, 1987), or possibly if periosteum is scraped off bone (Binford, 1981: 135). In such cases, multiple short nicks or long scrapes may be inflicted on the areas where the tissue adheres strongly to the bone. Knowledge of the soft anatomy is, therefore, important in interpreting these marks. In any case, filleting and sinew processing do not produce extensive, randomly distributed striations on bone surfaces.

Location
Numerous researchers have interpreted cut marks in particular locations on bones as indicators of activities such as: skinning; disarticulating; filleting; horn, antler or hoof removal; and sinew processing (Guilday *et al.*, 1962; Binford, 1978, 1981; Villa *et al.*, 1986; Bunn & Kroll, 1986; Olsen, 1987). If a whole assemblage is examined, patterns of meaningful placement of marks should begin to appear when systematic butchery rather than sedimentary abrasion is the cause. As Bunn & Kroll (1986: 436) have pointed out:

> The location and frequency of cut marks on different skeletal parts can be used in conjuction with knowledge of animal anatomy to identify patterning in the butchering techniques of present and past humans.

Sedimentary abrasion may be distinguished from these cultural processes by its more widespread occurrence over the diaphyses of long bones, irrespective of muscle origins and insertions or other attachments of soft tissue of the bone.

Orientation
Like location, orientation of cut marks is related to the particular task being conducted. Some preference for transverse striations has been noted for trampled bone (Brain, 1981: 17; Andrews & Cook, 1985), because long bones are more likely to rotate around their long axis than to move in other directions. We found considerable variation in directionality of the abrasion striations formed by our trampling experiments. Orientation of butchering marks depends on the task involved. Transverse cuts are common around joints, but oblique and longitudinal scraping marks may be associated with filleting and tendon removal.

Morphology and depth of marks

The striations produced in all of the above trampling experiments were extremely fine and shallow, regardless of the predominant size of the particles in the soil or the presence of large stones. The shallowness of the marks is probably due to the fact that all of the components in trampling abrasion (the bone, sediments and stone flakes) were mobile rather than fixed and no sustained pressure was inflicted. Marks documented by Oliver (1986), in which the cutting edges may have been in fixed positions, appear deeper. Theoretically, sedimentary grains might occasionally become temporarily affixed to the hoof of a large ungulate shortly before it encounters and tramples bones, with the result that deeper than usual trampling marks may be created. It is most unlikely that such an event would occur each time a bone or a particular assemblage was trampled, however. Thus, most trampling marks can be expected to be relatively superficial.

Most of the striations created by experimental trampling were smooth-walled and lacked the internal parallel lines associated with known cut marks. Many of the trampling mark superficially resembled chop marks or scraping, but were shallower than these humanly produced marks usually are. Chatter marks, like those seen on many scrapes made with a flint tool, were not observed in marks produced by experimental trampling. If chatter marks are occasionally created by trampling, we would expect them to be uncommon.

Association with polish

Extensive trampling of bone in abrasive sediments, whether wet or dry, may create a polish on the bone surface. Although polishes can form on bone from other processes such as handling, bone tool manufacture or use of a bone tool on soft materials (Olsen, 1984), a general polish on non-artifactural bone fragments may provide a clue that trampling or some other form of pedoturbation took place. Brain (1967, 1981) reported associations between polishing and trampling marks in his study, and Oliver (1986) recorded polish on his Holocene bones from Shield Trap Cave.

Intentionality

The intentionality of surface modifications on bone is difficult to measure or delineate in absolute terms. Nonetheless, we believe that sedimentary abrasion fails to reflect any predetermined purpose or intention. In contrast, a butcher attacks a carcass with certain goals that dictate various procedures in the same way that a flint knapper must take certain steps to produce a stone tool. There is no denying that muscles, tendons and other soft tissues are distributed in a standard fashion in relation to the skeleton. Even at the initial stages of tool use in butchery, hominids were bound by this fact. Although refinement of butchery techniques undoubtedly occurred through time, just as stone tool manufacture became more efficient, it is likely that even the earliest evidence for skinning and carcass dismemberment reflected intentionality and thus would not be expected to produce patterns of damage similar to those made by post-depositional sedimentary abrasion of bones. A deep slicing mark in an anatomically meaningful location can be just as diagnostic of human activity as are culturally derived features on a stone tool, such as a prepared platform, a given pattern of flake removal or retouch.

For the most part, our criteria for distinguishing between sedimentary abrasion and butchering marks involve macroscopic features on the bone surface. Even the morphology of cut marks can be discerned in some cases with the unaided eye or with a hand lens. Because sedimentary abrasion is generally very fine, however, it is best observed with a microscope at magnifications between 25 and 500 ×. Confirmation of the presence of internal parallel striations within a groove often requires microscopic analysis. We have found the SEM to offer resolution, depth of field and ease of photography far superior to those of optical microscopes.

It is important to note that each of the above criteria may not be recognizable in every prehistoric bone assemblage. Therefore, it is difficult to assign a minimal set of criteria for distinguishing between sedimentary abrasion and cut marks. In our view, the abundance, random placement and superficiality of many trampling marks is strikingly different from features of most true cut marks, so these are perhaps the most reliable as diagnostic traits. However, we would caution against heavy reliance on any one characteristic; the most confident assessments of unknown marks will be based on all available data.

Although it is possible that any form of pedoturbation which might press sharp-edged stone flakes against bone surfaces could mimic butchery marks, this would appear to be an extremely rare event under natural conditions. Even in reported circumstances that produce the closest cut mark mimics, we concur with Andrews & Cook (1985: 290) that "... provided the bone surfaces are examined with care, there should be no difficulty in distinguishing between them [cutmarks and trampling marks]", and with Bunn & Kroll (1986: 436) that, "... cut marks are not the randomly oriented, multidirectional, relatively shallow scratches that seem to typify abrasive trampling of bones by large animals."

Therefore, we conclude that, while trampling may have a great impact on spatial relationships of bone in archaeological deposits through movement, it is unlikely to produce striations deep enough and with a distribution, orientation, morphology and frequency likely to cause misinterpretation by knowledgeable observers.

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