Chapter 14
Primary Human Effects: Cutting Edge and Percussion Effects on Bone

Humans seldom eat vertebrates whole. Even animals weighing no more than a kilogram are broken into smaller segments before being chewed and swallowed. This pedestrian observation has broad implications for zooarchaeology. Bones of animals that humans consume often bear traces of how they were dismembered and their edible tissues were extracted. This chapter reviews what is known about the nature and causes of various primary human modifications to bone. It introduces distinctive bone surface modifications made by tools: cuts, scrapes, chops, and a range of percussion marks. I call these "primary human effects," in recognition of the temporal priority of these activities in relation to subsequent culinary processing reviewed in Chap. 15. "Primary" also acknowledges the greater antiquity in human history of tool-mediated carcass subdivision and percussion-aided nutrient extraction, which preceded cooking with fire by at least a million years. Chapter 15 will review heat-mediated processing and other tactics for enhancing the nutrient value or extending the use–life of animal foods. As with the signatures of nonhuman actors discussed in prior chapters, these chapters focus on distinctive human tool signatures and the contexts in which they are produced.

Butchery refers to human subdivision of vertebrate bodies into smaller units with tools. Research on butchery thus presents archaeologists with rich inferential possibilities, but these are fraught with interpretive complexities, and using clear terminology helps maintain important distinctions. Lyman (1987a:252) noted that butchery is not a single act but a sequence of activities. These actions are guided by a variety of considerations, including the anatomy of the animal, the implements at hand for processing it, the weather and time of day, the butchery site's distance from the final destination of the animal products, the intended uses of the animal's tissues, and so forth.

Some distinctions are useful to thinking about the sequence of operations involved in butchery. I refer to the first step in processing a carcass, usually shortly after an animal's death, as *primary butchery*, a generic term that applies equally well to hunters, pastoralists, farmers, or specialized meat processors. This is equivalent to Lyman's (1987a) "kill-butchery," also called "field butchery" by some

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working with hunters. Primary butchery may involve eviscerating, skinning, and dismembering the carcass and defleshing some of its parts.

Secondary butchery may take place at a different locale than primary butchery. For example, body segments transported to a caching locale may be further subdivided and trimmed at that locality to facilitate storage. Among hunters, carcass segments that served well for transport to a residential base may be subdivided according to the needs and desires of households sharing in the kill when those parts arrive at the camp. Secondary butchery can involve both dismemberment and defleshing.

Culinary processing (Chap. 15) is associated with cooking and eating animal bodies. It takes place not only at residential locales but also afield, as individuals or task groups sustain themselves while traveling to obtain resources away from their home bases. Hunters may consume snacks or meals during primary butchery, focusing on tissues that are liable to swift spoilage such as the brain and internal organs. People guarding cultivated fields a distance from a village may set up camp there, acquiring vertebrates during their time away from home and discarding bones in their field camps. Culinary processing involves further dismemberment and defleshing prior to cooking, reduction of bones by chopping and breaking to fit cooking containers and to liberate fat into stews, reduction of marrow-bearing bones by chopping and fracture, and exposure of bones to heat by variants on boiling, roasting, or baking.

Preservational processing, preparing meat, fat, or marrow to extend their use-life, is discussed in Chap. 15 and only briefly treated here with reference to evidence added during the chain of sequential butchery operations. Preservational processing includes meat stripping, drying, smoking with bone in or not, salting, pickling, mass marrow extraction, and bone grease extraction. Some operations leave distinctive signatures, while others do not.

Our knowledge of human modifications to bone has expanded through contemporary observations of actors in ethnoarchaeological and experimental settings. As with nonhuman bone surface modifications, SEM microscopy has clarified distinctive signatures of specific effectors. This chapter reviews basic morphological criteria of cutting and percussion modifications to bone. It leaves discussions of how to infer broader behavioral, social, and ecological contexts in which these modifications were produced for Part V.

14.1 Marks Made by Cutting Edge

Cutting marks can be inflicted on bone during dismemberment, defleshing, skinning, and removal of periosteum. The main intent of this chapter is to describe distinctive features of bone surfaces modifications at the effector/actor level of impacts. Discussion of the controversies over the functional meanings of cut mark patterning will be deferred until Chap. 19, which discusses inferring butchery from aggregate data.

Most actualistic research on distinctive criteria of cut marks has focused on stone tool marks. When referring to "stone tool cut marks," most researchers mean slicing marks made by cutting tools fashioned by percussion or pressure flaking, rather than by edges formed by grinding and polishing. Paleoanthropological researchers seeking to discern hominin behavior from sparse, Plio-Pleistocene evidence have done much of this topic's basic actualistic research. Their aim was to distinguish traces of hominin intervention from those of carnivores in palaeolithic African and Eurasian sites. More recently, zooarchaeologists studying societies in transition from stone to metal implements have explored the potential of cut marks on bone to elucidate how ubiquitous metal tools were in daily life by conducting parallel experiments.

Recognition of stone tool cut marks in 1981, and Binford's (1981) imputation of functional meaning to their placement on different skeletal elements (Chap. 15), led to a boom in studies discussing the behavioral contexts in which they had been made, especially among paleoanthropological researchers. Lyman (1995, 2005), wrote two thoughtful articles exploring the assertion that functional inferences could be made from cut mark frequencies. In these, he systematically investigated the placements and counts of cut marks and percussion marks on ruminant bones from multiple archaeofaunal samples from a total of eight archaeological sites in the Pacific Northwest of the U.S. His first study (Lyman 1995), compared archaeofaunas from three coastal Oregon sites with three from eastern Oregon, focusing on deer (genus *Odocoileus*) and wapiti *(Cervus elaphus*, known as "elk" in North America) and remains of like-sized ruminants. The second compared two more or less contemporaneous sites, Meier and Cathlapotle, within 10 km of each other on the lower Columbia River. Though Lyman found some statistically significant differences between the rates of occurrence of processing marks between coastal and inland sites that might arise from ecologically conditioned differences in the importance of ruminant-derived nutrients in the respective regions (Lyman 1995), however, he also found significant differences in cut mark frequencies in sites within the same geographic areas (Lyman 1995, 2005).

At the heart of the problem is the fact that, unlike chopping, sawing, or percussion marks, cut marks cannot be assumed to result from consistent and deliberate intention to impact the bone surface. Lyman concluded that cut mark analyses must be used along with other contextual evidence in *multivariate analysis* of butchery behavior, and not as a freestanding measure of intensity or intention of processing. Lyman's research thus cautions zooarchaeologists to avoid ampliative inferences about behavior from "cut mark intensity" and placement. The problem is not that cut marks do not ever convey useful information for reconstructing soft tissue removal. Rather, it's that their rates of occurrence and placements on skeletal elements are so highly variable, and generated in such presently unknowable contexts (was the bone and meat raw or cooked?) that using them to make higher-order inferences is often unwise. Those that do occur, taken together with other evidence for handling, may hint at, rather than establish, certain modes of carcass handling. Therefore, understanding their physical hallmarks is worthwhile.

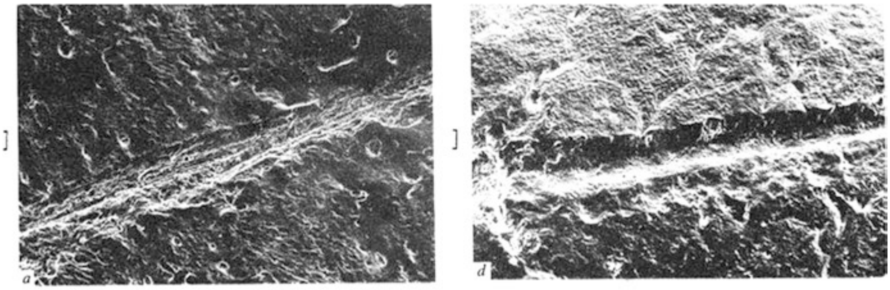

Fig. 14.1 An experimental stone tool slicing mark (**a**) and a hyena tooth score (**d**). Note striations in the cut mark, undulating chatter marks at base of the carnivore score mark. Brackets to the left of each micrograph represent 100 microns. (From Potts and Shipman (1981:578, Fig. 1), used with permission of the authors and Springer Publishing)

14.1.1 Flaked Stone Tool Cut Marks

The morphology of stone tool cut marks was described by Potts and Shipman (1981), Bunn (1981), Shipman and Rose (1983); see also reviews by Noe-Nygaard (1989) and Fisher (1995) on bone surface modifications. Shipman first applied SEM microscopy to defining morphological traits of stone tool marks (Fig. 14.1). Characteristics of stone tool cut marks noted by Shipman & Rose (1983) include:

1. Marks have most commonly V-shaped or oblique V-shaped cross-sections, but marks may occasionally be U-shaped (see below).
2. Stone tool marks show little crushing of bone into the groove of the cut mark.
3. Multiple striations lie in the groove, running generally in parallel to it.
4. Striations may deviate from the main groove on to the bone surface, as “shoulder effects.”
5. The beginning or end of the main groove may show striations diverging from the main cut (Fig. 14.2).
6. Relative to most carnivore tooth marks, cut marks are more elongated.

On the basis of further experimentation, one can add to these characteristics a relatively straight trajectory to the incision (Domínguez-Rodrigo et al. 2009, Chapter 13).

Stone tool edge morphology determines the cross-sectional shape and specific details of the cut marks they make. Walker and Long (1977)’s classic experimental study produced cut marks on fresh bone using metal implements, stone flakes with the unmodified edges, and stone tools with edges shaped (retouched) by further flaking, study the cuts with low-magnification light microscopy. They noted:

1. Unretouched flakes usually leave V-shaped marks.
2. Retouched tools leave more U-shaped marks, or, as Domínguez-Rodrigo et al. later (2009) put it, _/ shaped marks, which are wide but have relatively straight, oblique sides.

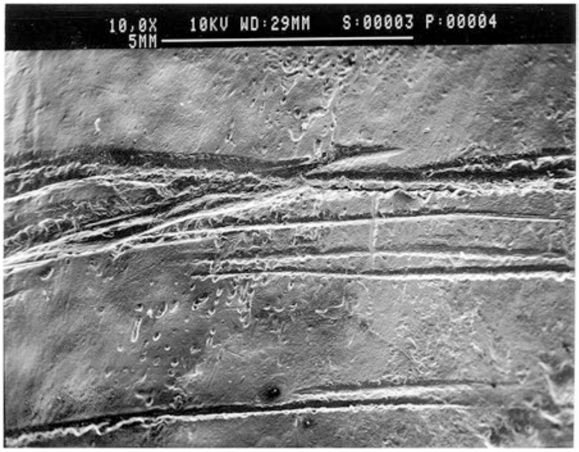

Fig. 14.2 Cut marks on bison thoracic vertebra, Koepke Site, I-74. Note sub-parallel striations within the main groove of the largest cut mark, "barb," and "shoulder effect" to left of and above main groove (Photo from Fisher (1995:13, Fig. 2a), used with permission of author and Elsevier)

Cut marks from retouched implements may display continuous exfoliation along part or all of the shoulder edge (Domínguez-Rodrigo et al. 2009, see Chap. 13).

The distinctive striations of stone tool cut marks are produced by irregularities in the stone tool edge that leave multiple fine lines in and at the edge of the main groove as the tool incises a bone surface. Even an unretouched flake edge has irregularities: flakes struck from a stone core are not flat but rather curved in profile, reflecting the wave of force that caused the flake release. A slicing action draws this curving edge over a section of bone, which contributes to multiple "paths" of striations, which may be may be augmented by edge damage or eminences in more granular raw materials. Retouched edges are even more complex: the ridges delimiting multiple small flake scars that shape a tool edge come into contact with the bone during a slicing action.

Haynes (1991:163) and Lyman (1994:297) stressed that Shipman and Rose's criteria derived from experimental study of direct cutting into bone, rather than from marks made incidental to cutting soft tissue during butchery. They note that not all distinguishing features noted in such experiments may be present in actual butchery cut marks, because the periosteum and other soft tissues can shield bone surfaces from the edge's impact. Shipman and Rose (1983: Figs. 5a, b) illustrate cuts into periosteum and the same marks on underlying bone after removal of the periosteum.

While some initially argued that SEM microscopy was the only accurate means of establishing that a mark was indeed inflicted by a stone implement, most zooarchaeologists have concluded that diagnostic traits of stone cut marks are recognizable under relatively low magnification light microscopy on well-preserved bone surfaces (e.g. White 1992; Domínguez-Rodrigo et al. 2009). I have been able to discern striations and barbs with magnifications ranging from a 10× hand lens to 50× light microscope. Some marks are indeed ambiguous when viewed at such low magnifications, and if a major research question can only be answered by determining the effector and actor, SEM examination can resolve such ambiguities (Blumenschine et al. 1996; Lyman 1987b).

14.1.2 Metal Cut Marks

Metal tool marks have been investigated using both SEM and more recently developed imaging techniques. Discerning whether metal tools were used to process an archaeofauna is relevant for several reasons. Shifts from stone- to metal-based butchery technology can entail reorganization of hunting, carcass processing, selective transport, and culinary strategies. This transition may indirectly reflect major changes in social relations: not everyone in a community may possess esoteric metallurgical knowledge and technical skills, thereby differentiating those with such knowledge and skills from others. Some groups obtain metal tools by exchange with metallurgical specialists in other societies, which may intensify raw material and commodity production in the recipient society, as well as inter-societal relations. Finally, access to high-value metal tools can vary within a community, according to the wealth and social networks of different households. Intra-community variation in metal-mediated versus stone-mediated carcass processing may shed light on social asymmetries at the level of households or gender (Gifford-Gonzalez 1989b).

The earlier literature (Binford 1981; Gifford-Gonzalez 1989a; Lupo 1994; Walker and Long 1977) reached a consensus about metal cut marks:

1. They lack fine striations within the groove.
2. They are often more steeply V-shaped in cross-section than are stone tool marks.
3. They often have an obliquely angled cross-section.

Further research expanded on typical features of metal tool marks on bone. S. L. Olsen (1988) used SEM microscopy to examine marks made during bone tool manufacture, including those created by metal implements, revealing distinctive scrape marks compared to those made by stone implements. Greenfield (1999) experimentally explored effects of metal cutting edges of varying types, scalpels to large knife blades, as well as smooth versus serrated knife edges, reporting SEM microscopy findings for simple metal blade effects:

1. Metal blades generally produce either a narrow V-shaped groove with a distinct apex at the bottom of the mark (Fig. 14.3). In the case of duller edges, metal blades can produce a more square, [_]-shaped groove with a flat bottom.
2. Metal blades produce more uniform cuts.
3. Metal blades tend to build up a ridge of bone to one side of the incision that Olsen (1988) called "crushing-up" (Fig. 14.4), a more ubiquitous trait of sharp, straight metal cutting edges than of stone tool cut marks. Greenfield notes that stone tool cuts may appear dirty under magnification due to a trail of microdebris in the groove (Greenfield 1999:804).

Although metal cut marks lack the striations typical of stone tool cut marks, metal knives with dull or damaged edges may leave one or more parallel grooves within the main cut, which might be mistaken for stone tool marks by those unfamiliar with lithic cut marks on bone. The grooves within a metal cut differ from striations by normally being consistent in their placement throughout the entire cut

Fig. 14.3 Metal cut marks on the anterior face of a caprine lunate (carpal bone) at 20× magnification, showing cut marks in a z-pattern on the bone. Specimen from the seventeenth century Spanish colonial era site of Paa-ko/San Pedro (LA-162), Bernalillo County, New Mexico (Photo by Jun Sunseri, used with his permission)

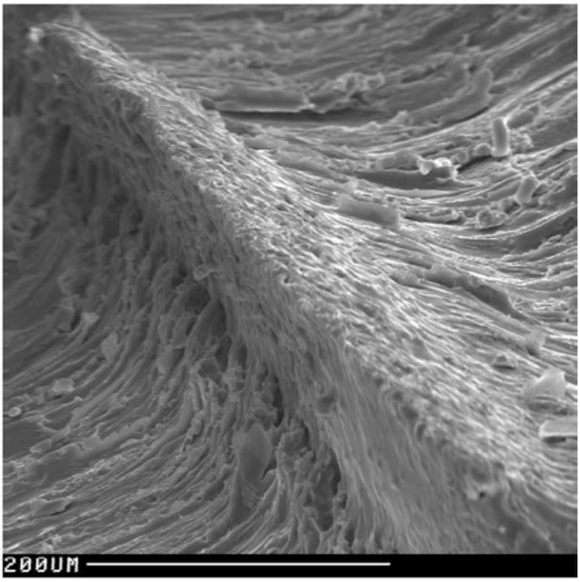

Fig. 14.4 SEM micrograph of modern metal knife cut mark at 200× magnification, showing the crushing-up of a section of bone cut by the blade (Greenfield 1999:801, Fig. 3, used with permission of author and Elsevier)

and not "shouldering out" as do stone tool striations. Figure 14.5 illustrates a metal tool mark on conjoined caprine cranial fragments from a seventeenth century colonial site in New Mexico. Forensic anthropologist Alison Galloway (personal communication, 2002) notes that such marks are relatively common in criminal cases, as perpetrators may resort to relatively dull kitchen knives or craft-bench tools at hand when hurriedly breaking down a victim's body.

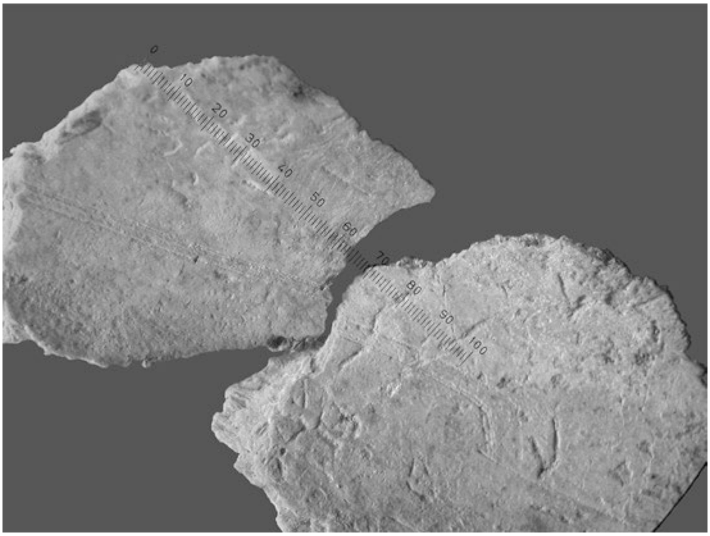

Fig. 14.5 Metal cut mark on caprine cranial fragments at 10× magnification, showing a broad mark with a consistent, unshouldered parallel groove within the main scar. Such marks are made by dulled or damaged metal tool edges. Scale calibration in mm. Specimen from the seventeenth century Spanish colonial era site of Paa-ko/San Pedro (LA-162), Bernalillo County, New Mexico (Photo by Jun Sunseri, used with his permission)

14.1.3 Scrape Marks

The same stone and metal edges as can incise bone surfaces can produce scraping marks when their edges are dragged at an angle across a bone surface. Scraping accomplishes a number of goals during carcass processing, including during disarticulation, when clearing off soft tissues before cutting a tendon or ligament at a joint, or during marrow extraction, when scraping periosteum off a long bone surface before striking it with a percussor to break the bone (Binford 1981). Shipman and Rose (1983) characterized scrapes made by stone flakes:

1. They display broad, shallow grooves over 1 cm^2 or more.
2. The have parallel striations in sets, possibly with multiple, differently oriented sets intersecting in the scraping scar (see also Lyman 1987a).

The nature of the tool and its orientation to the bone surface condition the configuration of marks produced. Figures 14.6 and 14.7 show differences in modifications produced by different stone tool forms and edge orientations.

Christidou (2008), who has investigated Late Neolithic and Bronze Age fauna in the Balkans, reported on experiments with bronze replicas of cutting and engraving tools found in regional sites. Experiments included scraping, whittling, grooving, and percussion of sheep/goat metapodial bones, with scraping tools applied at different angles to the bone surface. Resulting marks were examined under a 5-50×

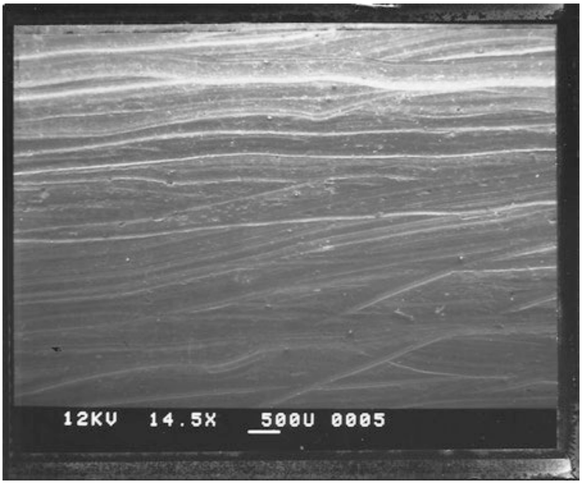

Fig. 14.6 SEM micrograph of fresh bone scraped with an unmodified flint blade. Scrape shows longitudinal striations typical of cuts with stone tools, but with the flake held more or less perpendicular to the surface of the bone. Striations thus cover the entire scraped surface, rather than being confined to a cut. White bar in footer is 500 microns. (Unpublished SEM micrograph by Sandra Olsen, used with her permission)

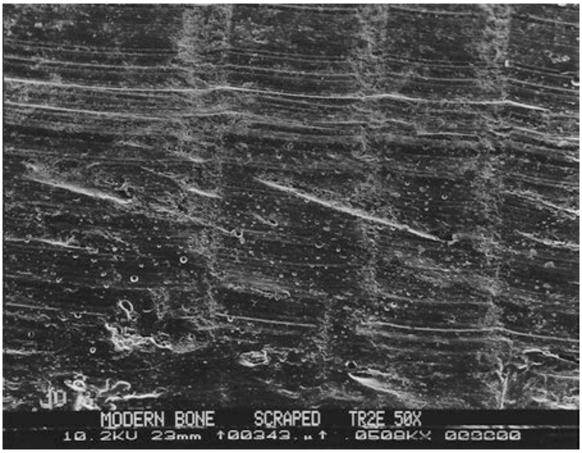

Fig. 14.7 SEM micrograph showing longitudinal striations made on fresh bones by scraping with a flint burin, or engraver. Horizontal striae are micro-cuts from the edge of the tool; vertical lines are chatter marks created as the tool skipped repeatedly across the bone surface. Blurred bar in footer bar: 1000 microns. (Unpublished SEM micrograph by Sandra Olsen, used with her permission)

stereoscopic light microscope, and with a metallographic microscope using Differential Interference Contrast (DIC) polarized light microscopy at 200× magnification, which produces a somewhat three-dimensional view that enhanced features of tool traces. Christidou (2008:750) summarizes features of the experimentally produced modifications: metal tool scraping marks exhibit a generally more uniform pattern of scratches than marks made by stone tools and may include chatter marks (Fig. 14.8). Repeated scraping with metal tools produced polish by spreading and smoothing cortical bone fragments along the bone surface.

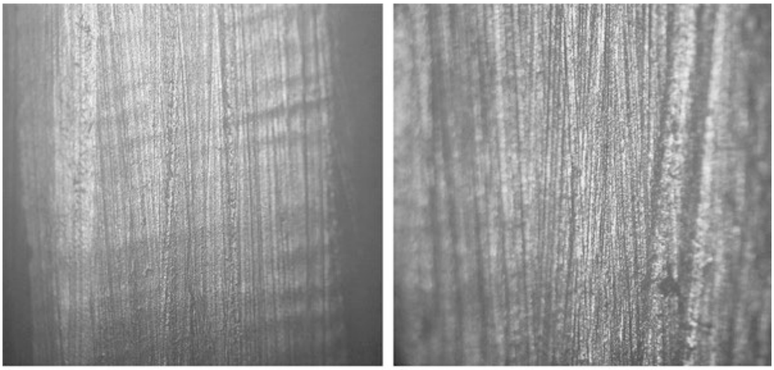

Fig. 14.8 Caprine metapodial surfaces scraped by bronze knife blade, micrograph taken with stereoscopic microscope. **1** 12.5×; **2** 40× magnification (From: Christidou (2008:736, Fig. 2), used with permission of Elsevier)

14.1.4 Chop Marks

Chop or hack marks are percussion marks inflicted by sharp-edged tools and have been recognized as a distinct form of butchery modification for many years (e.g. Guilday et al. 1962). Chops or hacks can be made with either stone or metal tools. Chop marks may be inflicted during primary butchery, during disarticulation of joints, or removal of edible tissues from larger animals. Frison (1970) argued that prehistoric peoples of the Great Plains used chopping to swiftly remove quantities of meat from mass bison kills. Chopping can also occur in secondary or culinary carcass processing. Depending upon the nature of the cutting edge and mass of the tool, chopping can break down skeletal units for social distribution (Bartram 1993; Yellen 1977), to fit them into a cooking pot (Bartram 1993; Yellen 1977; Marshall 1986), or to open marrowbones (Yellen 1977, 1991). Binford (1981) recorded chopping with metal hatchets as a regularly applied tactic for breaking up frozen segments of butchered caribou among the Nunamiut.

As with other forms of percussion, chopping may not leave tool marks on all fragments it produces. Chop marks are inflicted to the depth that a chopping tool penetrates the element struck, and the force front perpetuated by its blow creates a typical break surface through the balance of the element. Bone that is successfully chopped through generally displays:

1. A planar, flat surface on the chop mark itself. Walker and Long (1977) report a higher depth-to-width ratio of chop marks as opposed to cut marks, and Shipman and Rose (1983) report that chop marks are wider than cut marks at top.
2. If compact and cancellous bone tissues are transected, both are flattened in the same plane. This contrasts with the response of these respective tissues to blunt percussion. If cancellous bone is chopped, some trabecular tissue may be crushed into adjacent pore spaces.

3. Fractures may arise and run on from the point of deepest penetration of the tool mark, showing a discernible shift in the surface contour of the break.

I have found that *unsuccessful* chop marks often reveal more of the shape of the chopping tool than do successful chops, which dissociate the cross-sectional evidence of the tool.

A single tool used for chopping can sometimes be employed in finer-grained cutting as well, thus leaving two disparate signatures. A good example of this is the Asian metal cleaver. Most non-Asians view this implement as a chopping tool, but it is actually used for filleting, fine slicing, and dicing. At the experimental zooarchaeology workshop that I ran outside Beijing in 1992, Chinese colleagues shunned my knife in favor of the more familiar – and very sharp – cleaver for skinning a goat. They quickly accomplished the skinning operation with a minimal number of cleaver cuts to the skin, combined with skilled manual separation of connective tissue holding integument to the rest of the carcass.

14.1.5 Saw Marks

In sawing, the force applied by the tool moves back and forth at an acute to right angle to the orientation to the bone surface, normally with downward pressure and in constant contact with the bone surface. These marks can be made with stone or metal tools. Carcass processing using metal saws is the hallmark of urbanized European butchery for centuries: medieval European paintings and stained glass windows attest to butchers' use of metal saws to break up carcasses of pigs and cattle. Sawing sections of one or more skeletal elements to produces the finished, bone-in cuts of meat with which Westerners are familiar (Gust 1983, also see Fig. 14.9).

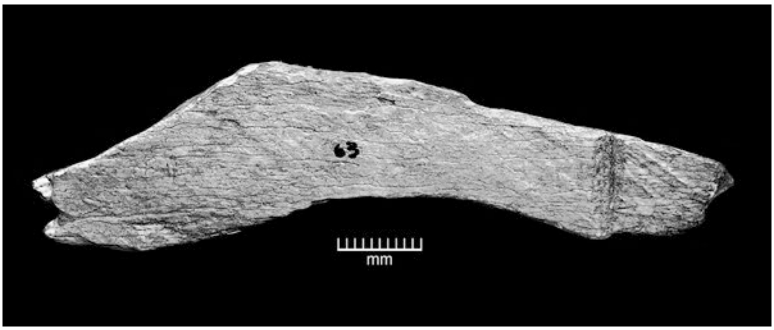

Fig. 14.9 Fragment of a flat bone of a very large mammal, showing a broad stone tool saw mark, striations from sedimentary abrasion, Behrensmeyer Weathering Stage 3. Bone associated with an Upper Pleistocene Aterian lithic industry locality near Adrar Bous, Niger. (Photo by Don Harris, of a specimen collected 1970 by J. D. Clark, in an assemblage analyzed by the author)

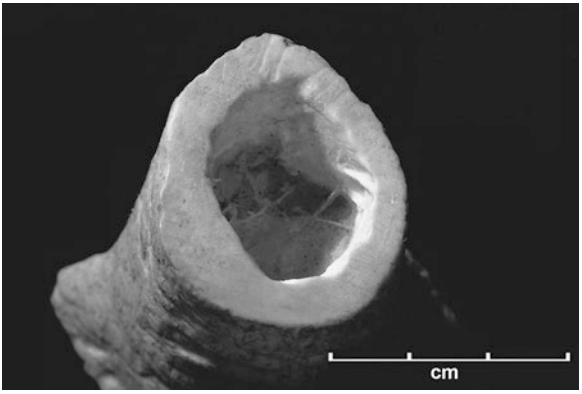

Fig. 14.10 Close-up photograph of a modern long bone cut with a metal band saw, showing the plane, flat surface, and fine parallel striations across the surface made by the saw teeth. This specimen's surface is overprinted by some angled carnivore tooth scores on the upper right quadrant on the circumference, as well as rounding and polishing of bones due to carnivore gnawing and licking. Scale shows 1 cm intervals. (Photo by Don Harris, of a specimen collected by the author)

Stone tools and metal ones can leave sawing marks with the following characteristics:

1. Stone tools used in a sawing motion leave a wide scar, usually in a parallel series, with striations (Walker and Long 1977).
2. Stone tool sawing marks may have an undulating aspect when viewed from above.
3. Serrated metal sawing tools produce regular, fine parallel striae across the flat sawed surface. Gust (1983) illustrates historic saw marks on butchered bone compared with those produced by a modern band saw. Historic marks are generally coarser than modern saw marks.
4. Bones sawed with metal tools display "hinges" on sawed and then broken surfaces, chipping, oblique or straight angles, and incomplete stroke marks.
5. Under magnification, the surface of sawed cancellous tissue displays small bone fragments crushed into the trabeculae transected by the saw (Figs. 14.10 and 14.11).

14.2 Products of Percussion: Hammerstone Notches, Pits, Anvil Damage

Percussion by humans is dynamic loading via hard percussors, aimed at breaking open skeletal elements to extract within-bone contents. Hominins have been hitting diaphyseal segments of marrow-bearing long bones with hammerstones for well over two million years (Blumenschine and Selvaggio 1988), a practice that continues to the present day. Percussion results in an array of bone surface modifications with specific morphological features (cf. Blumenschine and Selvaggio 1988, 1991;

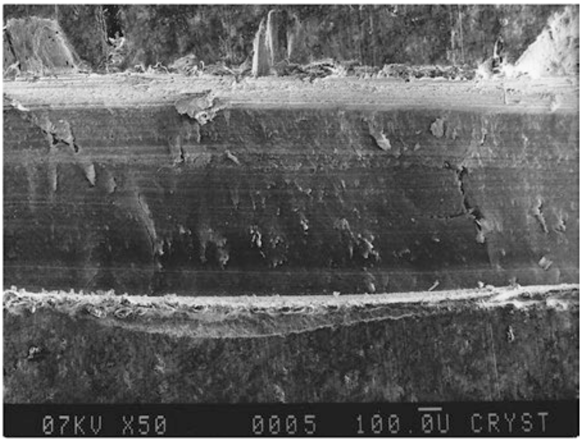

Fig. 14.11 SEM micrograph of a toothed metal saw mark on fresh bone, with broad, consistently straight-sided marks of individual saw teeth along the top edge of initial contact, with crushing-up of bone tissue at both edges and crushing of bone tissue into the mark. Note that parallel striations in the bottom of the saw mark are nearly perfectly straight for extended distances. Scale bar on footer = 100 microns (Micrograph by Sandra Olsen, used with her permission)

Fisher 1995; Lyman 1994). Controlled experiments (Galán et al. 2009; Blasco et al. 2014; Pickering and Egeland 2006) have augmented descriptions of their diversity in form and added greater complexity to identifying the mechanical causes of specific marks.

Ethnoarchaeological and experimental observations show that, in the absence of ground or metal stone chopping tools, one of several tactics may be applied to break long bones. One is striking an element in the hand with a percussor, as Binford (1978, 1981) reports is typical of Nunamiut processing fresh caribou elements. A widely used approach involves resting an element on an anvil of stone or bone and striking its upper side with a percussor. Stone anvils enhance the fracturing potential of a hammerstone blow by reflecting the force transmitted through the bone to the anvil back into it (Johnson 1978, 1983; Mengoni Goñalons 1980). Chapter 11 described that some force introduced into a long bone cylinder by percussion winds around and along the element, as other force runs transversely across the bone. If this meets an anvil, it rebounds into the element, amplifying a single blow's stress on the cylinder. Another technique is striking a skeletal element against a stationary rock anvil (Blasco et al. 2014). Readers may be more familiar with outcomes of striking a bone with a stone or other hard object, but less so with striking a stone or other hard anvil with a bone. Both are approaches will be discussed here.

Blasco et al. (2014) undertook experimental trials to compare fracture and bone surface modification of hammerstone percussion, both with and without an anvil, to those produced by anvil clubbing percussion (Oliver 1993), or, as Blasco et al. call it, batting percussion (readers from cricket- or baseball-playing countries are permitted a moment to adjust their referential frames). Six individuals with no prior experience with breaking long bones each fractured four fresh humeri, four

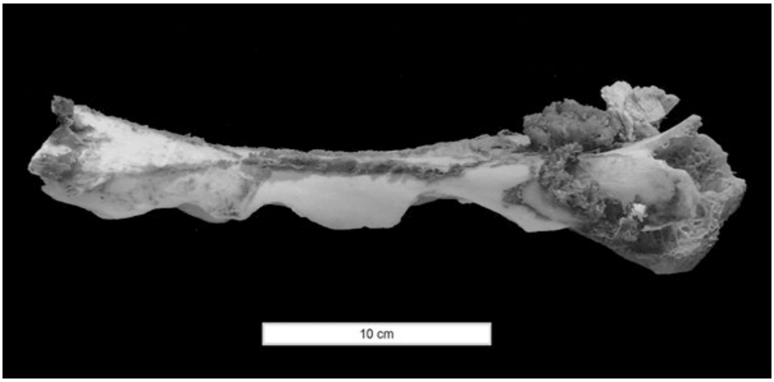

Fig. 14.12 Femur of topi (*Damaliscus lunatus*) from a modern foraging campsite near Koobi Fora, East Lake Turkana, Kenya, showing three hammerstone impact notches (Photo Don Harris of a specimen collected by author)

radioulnae, four femora, and four tibiae of mature domestic cattle using each of the approaches. They were given little instruction in procedures, and their intuitive choices and learning curves were documented. In the batting/clubbing experiment, the experimenters held the element in both hands and struck it against a limestone anvil with rounded edges until the bone broke. If the element did not break on the first try, all actors chose to keep striking the same part of the long bone on the anvil until it did. On average, actors assigned bones in the batting/clubbing experiment broke them in one-third the time spent breaking bones using hammerstones; average time to fracture was less than 30 s.

Bone surface modifications produced by all forms of percussion result from the interaction of an element and its surface with a hammerstone, an anvil, and/or a stone against which it is struck. These interactions produce larger and smaller marks that testify to the use of percussive force and are outlined below.

14.2.1 Hammerstone Impact Notches

Impact notches, or, more neutrally, "loading points," are the most distinctive percussion marks. Such marks usually are semilunar concavities along the broken wall of a diaphysis. In direct or anvil percussion, depending upon the relation of diaphysis size and strength to strength of the hammerstone wielder, and also the processor's expertise, only one blow may be sufficient to crack a long bone open. Several blows may be required to weaken the cylinder, and each blow will be reflected in a distinctive notch (Fig. 14.12). These are actually flake scars (see *Percussion Flakes* below). Capaldo and Blumenschine (1994) provide a comprehensive review of zooarchaeological discussions of notches up to the point of their article. Pickering and Egeland (2006), Galán et al. (2009) and Blasco et al. (2014) augment this review and add more experimental results.

Earlier experiments concluded that notches were formed only on the side of a long bone directly struck by the hammerstone, with the associated flake or flakes driven off on the endosteal side of the bone. Later experiments by Galán et al. (2009) have raised the possibility that, occasionally, impacts can create notches on both hammerstone- and anvil-sides of a long bone, or opposing notches.

As might be expected, the clubbing/batting approach of the Blasco et al. (2014) study produced some bone surface modifications similar to hammerstone percussion and some that differed. Percentages of impact notches were actually similar in the hammerstone and batting assemblages, but the proportions of multiple notches differed. The combined hammerstone sample had 70% single notches and 28% multiple, overlapping notches, whereas the reverse was the case with the batting assemblage, which displayed 70% overlapping notches and 30% single notches (Blasco et al. 2014: 1077). This is due to the repeated striking of the same part of the element against the anvil described above. The hammerstone sample had 2% opposing notches, per Galán et al. (2009), whereas the batting sample had none. Divergences were also seen in the relation of notches to the long axis of the element: batting percussion, "concentrates impacts on transverse planes," whereas notches from hammerstone percussion "occur on all type of planes, except on transversal ones" (Blasco et al. 2014: 1099).

14.2.2 Percussion Flakes

Other traits are associated with impact notches. Most apparent are those small percussion flakes detached from the medullary side of the diaphyseal wall at the impact point, which create the notches described above (Fig. 14.12). Fisher (1995:21) notes that percussion flakes, "display the same basic technical attributes of percussion as occur on flakes of knapped fine-grained stone" (Fig. 14.13):

1. They display a platform at the impact point and a bulb of percussion below the platform.
2. They sometimes show "ripple" marks and/or hackle marks originating at or near the platform or bulb.
3. Such flakes usually are side-struck (wider-than-long) in morphology and may display stepping at their distal ends.

In Blasco et al.'s hammerstone sample, impact flakes accounted for 13% of all diaphyseal fragments, whereas they accounted for only 0.9% of all fragments generated by batting bones against an anvil (Blasco et al. 2014: 1089–1093).

Another type of damage at the impact point is crushing along the outer wall of the diaphysis, which may be discernable as isolated pits (see below) or may be a continuous field of such damage.

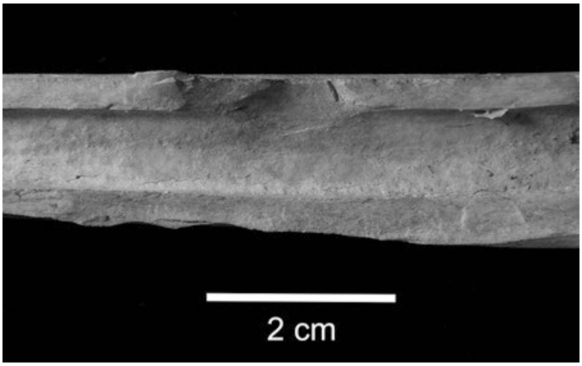

Fig. 14.13 Percussion flake scar on endosteal side of a pronghorn (*Antilocapra americana*) metatarsal from the Lost Terrace site, Montana. Note the typical side-struck form, with breadth greater than depth in relation to the direction of force. (Photo by John L. Fisher, used with permission)

14.2.3 Anvil Counterblow Damage

The in-bound force from a percussor blow often interacts with the force rebounding from an anvil to cause shatter on the outer surface of the anvil-side diaphyseal wall. This "counterblow" damage to a long bone differs from that of a hammerstone impact, often manifesting as angular shatter on the outer side of the diaphysis wall rather than as conchoidal flakes detached on the inner, medullary side of the wall.

14.2.4 Percussion Scratches and Pits

Hammerstones and anvils may be stones with irregular surfaces or smooth cobbles. When the initial blow drives a bone against an anvil, several marks are possible. Prominences on the stone dig into the bone surface, often dragging across it with lateral movement of bone with the swinging blow by the hammerstone. Turner (1983) termed such marks "anvil scratches" on the assumption that these appeared exclusively on the anvil side of diaphyses. Blumenschine and Selvaggio (1988, 1991) defined percussion pits and depressions with "microstriations" associated with hammerstone notches (Figs. 14.14 and 14.15). Pickering and Egeland (2006) follow White's (1992) separation of these percussion marks into two types, pits and striae fields, while acknowledging that these categories may overlap. They determined that the majority (68%) of percussion pits on experimentally fractured deer long bones were from the anvil side of experimental bones, as were striae fields (72%), while around one-third were associated with hammerstone impacts on the upper surface of the long bone.

Percussion pits with striations leading out of the pits were originally seen as a hallmark of this modification (Fig. 14.15). However, Galán et al. (2009) explored the consequences of using smooth- versus rough-textured hammerstone-anvil combinations. They found the same percussion marks documented by other researchers but also a third type of percussion mark, a pit without microstriations (Fig. 14.16).

Fig. 14.14 Experimentally produced stone anvil percussion pits (right) and striae field (center) on a bovid long bone, at c. 16× magnification (Photo from Blumenschine et al. (1996:498, Fig. 2d), used with permission of Elsevier)

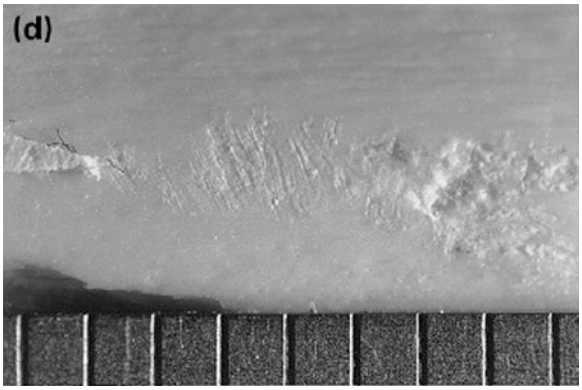

Fig. 14.15 SEM micrograph of anvil percussion pit with diagnostic microstriations leading out of the pit, reflecting the friction of the anvil across the bone surface during impact. Scale: 150 microns. (Micrograph from Blumenschine and Selvaggio (1988:763, Fig. 1c, used with permission of Elsevier)

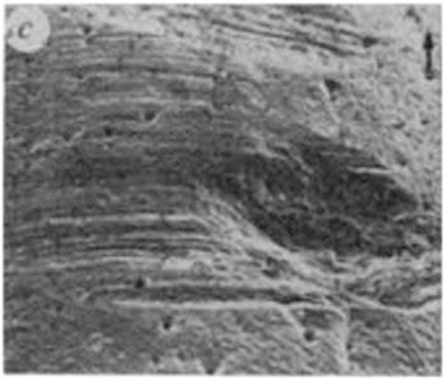

Fig. 14.16 Percussion pit on unmodified bone without striations. Scale: 1 mm (From Galán et al. (2009:783, Fig. 6, used with permission of M. Domínguez-Rodrigo and Elsevier)

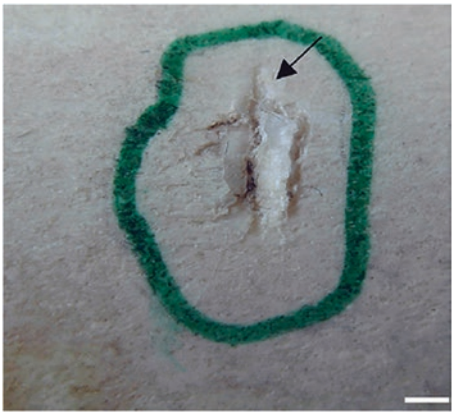

Fig. 14.17 SEM micrograph of jagged surface and striations on deer antler beam, produced by its use as a soft-hammer percussor for stone artifact production by Sandra L. Olsen (1989:132, Fig. 7). Scale: bar is 1000 microns. Compare with Fig. 13.13 for natural antler modification image. (Used with permission of S. L. Olsen and Elsevier)

These were the least common percussion mark in both hammerstone-anvil sets, with pits with associated striations and striae fields being more common. In the smoother hammerstone-anvil experimental set, pits without microstriations are from five to nine times as common as they are with angular hammerstones (a chopper and a polyhedron) and anvils.

Blasco et al. (2014: 1093) report that their batting/clubbing assemblage had percussion pits on 12% of all of fragments, and that most lacked associated microstriations. They state that some, "display similar features to chop-marks," explaining this by the fact that, "they are also generated by the application of a dynamic and/or percussive force against an angled edge." Some percussion pits are "variable geometrically shaped marks," 2–30 mm in maximum dimension.

14.2.5 Clubbing by Bone or Antler Tools

S. L. Olsen's (1989) actualistic research and application of SEM to specimens established that it was possible to distinguish between modifications to deer antler made during life from those made during the human use of deer antler as percussors in producing stone artifacts. Figure 14.17 shows the jagged and striated surface of an experimental antler percussor used to flake flint, which can be compared to the generally smooth surface of the *in vivo* modifications (Fig. 13.13). Olsen noted that, at high magnification, embedded chips of stone could sometimes be seen in percussors.

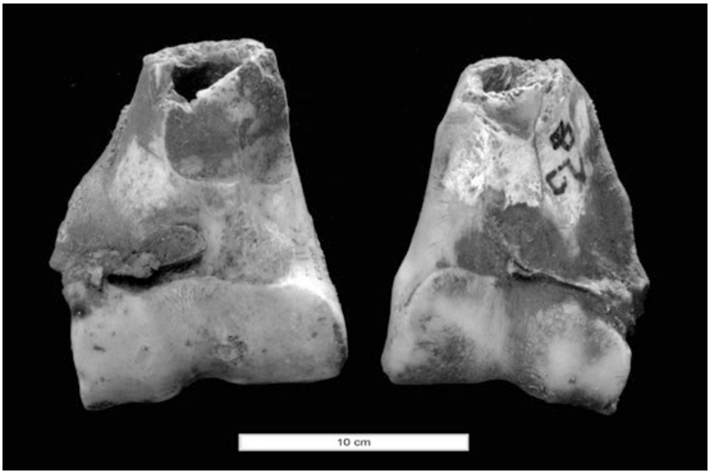

Fig. 14.18 Two common zebra (*Equus quagga boehmi*) distal humeri from Site 105, a modern pastoralist encampment near Koobi Fora, East Lake Turkana, Kenya, showing redundant patterning in transverse fractures at distal shafts, rebound flake scars from an anvil, and abrasion to the break surface, possibly due to ungulate trampling (Photo by Don Harris, of a specimen collected by the author. Reproduced with permission of the Center for the Study of the First Americans, Texas A & M University)

14.2.6 Fracture Outlines

Experimental research has found that hammerstone percussion on fresh bone, with or without anvils, generally results in spiraling fractures of varied lengths and termination forms, depending upon a skeletal element's osteonal organization and the amount of force loaded on the bone cylinder. Smooth break surfaces accompany these break outlines. As noted in Chap. 11, transverse breaks occur when the stress loaded exceeds an element's capacity to transmit strain longitudinally. (Fig. 14.18)

Blasco et al. (2014) report that batting/clubbing percussion produced transverse diaphyseal fractures at more than twice the rate as did hammerstone percussion: 36.7%, compared to 16.6% with hammerstone percussion, and of jagged fracture surfaces: 21.3%, compared to 3.9% (Blasco et al. 2014: 1092). Batting/clubbing produced fewer diaphyseal fragments than did hammerstone percussion. However, diaphysis repeatedly struck against an anvil, multiple bone splinters were driven into the marrow. I suspect that the splintering rate would have decreased with more effective initial strikes, had the experimenters further developed their skills. Blasco et al. (2014) found such a learning curve, though noting that actors with greater body size and strength – some were sports team members – tended to produce fractures more swiftly.

14.3 Problems of "Equifinality"

Chapter 13 discussed the apparent equifinality between marks produced by trampling and cut marks inflicted by stone implements, and how further experimental work has clarified differences between the two, using multiple variables and contextual information (sedimentary matrix). Zooarchaeologists have likewise cautioned about assuming human agency from notches on bones, which cannot only be produced by nonhuman carnivores but also by geological forces. Hammerstone impacts can be perfectly produced on fresh bones by falling rocks in caves (Oliver 1989), and, if such an element were resting on a rocky substrate, such an impact might even produce anvil damage. In this case, the effectors and causal processes are very similar to human dynamic loading, producing virtually identical result.

Very large-toothed carnivores such as modern large cats and hyenas can produce flakes and flake scars by static loading, that is, a form of pressure flaking, as noted in Chap. 11, see Fig. 14.13). Capaldo and Blumenschine (1994) compared experimentally produced hammerstone impact notches with those produced by hyenas and lions on long bones of small-to-medium-sized and large bovids. They determined that hammerstone-produced flakes had more obtuse release angles than did those produced by carnivore teeth. For small to medium-sized bovids, notches produced by hammerstone were broader than those produced by hyena teeth at a statistically significant level, although ranges of the two overlapped. For larger bovids, the same trend was seen, but not at the level of statistical significance. Capaldo and Blumenschine (1994:730) stipulate a conservative definition of percussion flakes:

> …a single bone flake or a nested series of flakes, leaving a negative flake scar that extends through the entire thickness of the bone and onto the medullary surface…. Normal notches, therefore, exclude flake scars on the cortical surface of bone (inverse retouch on lithic artifacts) and indentations emanating from or restricted to the bone thickness. We refer to these latter forms as pseudo notches.

Pickering and Egeland (2006) follow the same definition but argue from their experimental observations that some pseudo notches are definitely percussion products, and that these may be more common on some skeletal elements, such as ruminant radii, than others. They agree with Capaldo and Blumenschine that percussion and carnivore tooth flakes show sufficient overlap that a prudent course is to place them into an ambiguous category. Both sets of researchers and Fisher (1995) suggest that the best way to discern the identity of the actor is to inspect notched specimens for other surface modifications typical of nonhuman carnivores (scores, pits) versus hominin (anvil pits, striations) handling.

In such cases of ambiguity, multiple lines of evidence, such as associated cut or tooth marks or other aspects of physical context, may clarify the effector and actor. This was called a "configurational approach" by Domínguez-Rodrigo et al. (2010) and a "forensic approach" by myself and Lyman (Chap. 3). Nonetheless, analysts should accept that the causes of some modifications might remain ambiguous. In such cases, it is prudent to use descriptive terms for equivocal evidence that do not specify the actor or effector. I have done this working with one taphonomically complex assemblage where sedimentary abrasion has so altered carnivore or human marks on some specimens that I stipulate "indeterminate mechanical damage" as a bone surface modification option.

The next chapter introduces culinary processing and advocates for a *chaîne opératoire* approach to animal carcass processing.

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