The use of bone surface modifications to model hominid lifeways during the Oldowan

By: Charles P. Egeland

Abstract:

Ever since the ground-breaking taphonomic work of Bunn (1981) and Potts (Potts and Shipman, 1981) documented cut marks on bones from early Pleistocene deposits at Olduvai Gorge and Koobi Fora, bone surface modifications have played an increasingly prominent role in understanding the formation of Oldowan faunal assemblages. The analysis of surface modifications, which include most prominently hominid butchery (cut marks, percussion marks) and carnivore (tooth marks) damage, can address many important issues in Oldowan archaeology, including (1) Which carcass resources did Oldowan hominids exploit? (2) How often did they obtain carcasses? (3) When they did acquire carcasses, did hominids have their choice of resources, or was the menu limited to what was available after other carnivores had had their fill? (4) What was the nature of the interaction between hominids, as a relatively new member of the large carnivore guild, and Plio-Pleistocene carnivores? These questions, and thus the analysis of bone surface modifications, must be integrated into any model that seeks to shed light on the socioeconomic function of Oldowan sites.

Keywords: Oldowan | hominids | Plio-Pleistocene | taphonomy | bone surface modifications

Chapter:

***Note: Full text of chapter below

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Ever since the ground-breaking taphonomic work of Bunn (1981) and Potts (Potts and Shipman, 1981) documented cut marks on bones from early Pleistocene deposits at Olduvai Gorge and Koobi Fora, bone surface modifications have played an increasingly prominent role in understanding the formation of Oldowan faunal assemblages. The analysis of surface modifications, which include most prominently hominid butchery (cut marks, percussion marks) and carnivore (tooth marks) damage, can address many important issues in Oldowan archaeology, including (1) Which carcass resources did Oldowan hominids exploit? (2) How often did they obtain carcasses? (3) When they did acquire carcasses, did hominids have their choice of resources, or was the menu limited to what was available after other carnivores had had their fill? (4) What was the nature of the interaction between hominids, as a relatively new member of the large carnivore guild, and Plio-Pleistocene carnivores? These questions, and thus the analysis of bone surface modifications, must be integrated into any model that seeks to shed light on the socioeconomic function of Oldowan sites.

The role of bone surface modifications in understanding faunal assemblage formation

The process of faunal assemblage formation can be usefully understood in three distinct, albeit interdependent, components (Egeland et al., 2004: 345). The first is carcass acquisition. This involves gaining access to a carcass regardless of the mode of that access (e.g., hunting or scavenging) or the nutritional condition of the carcass (e.g., fresh or desiccated). The second is carcass accumulation. Here, a carcass or carcass part is transported to

and eventually deposited at a particular locale on the landscape. The third component is carcass modification, which occurs when bones or parts thereof are broken or partially/wholly destroyed. It is during this last process that bone surface modifications are created.

Two important points must be made here. First, carcass modification, and thus the infliction of bone surface modifications, can occur at any stage of assemblage formation. Second, the modification component of assemblage formation is the most directly inferred because bone surface modifications provide one of the few unambiguous taphonomic indicators of hominid and carnivore involvement with bones (assuming, of course, that they can be correctly identified; see discussion later). What flows from this is the realization that the formation of a faunal assemblage, be it Oldowan or Neolithic, simply cannot be addressed with any rigor without the analysis of bone surface modifications.

The role of actualism in identifying and interpreting bone surface modifications

The perspectives offered in this chapter are all guided by actualism, which involves "observing present-day events and their effects in order to give meaning to the prehistoric record" (Gifford, 1981: 367; see also Simpson, 1970; Lyman, 1994: 46–69; Pobiner and Braun, 2005a). Because it provides unambiguous linkages between traces (e.g., a mark on a bone), causal agencies (e.g., a stone tool slicing a bone), effectors (e.g., a sharp-edged flake), and actors (e.g., a hominid wielding a stone tool; terminology follows Gifford-Gonzalez, 1991), actualism, and the uniformitarian assumptions that accompany it, provide *the* critical referential framework for understanding past processes.

Marean (1995) has provided a useful distinction between naturalistic and experimental actualism. Experimental studies directly control the variables that produce the observed traces, as in studies that purposely vary tool raw material to examine differences in cut-mark frequencies between, for example, obsidian and flint flakes (Dewbury and Russel, 2007). Naturalistic research observes actors and their resultant traces but does not intentionally manipulate the variables. An excellent example of this form of actualism is found in Blumenschine's (1986) observations on the natural sequence by which carnivores in the Serengeti ecosystem consume different carcass parts. As we will see, actualistic studies, both experimental and naturalistic, play a central role in reconstructions of hominid butchery behavior and hominid/carnivore interactions in the Oldowan.

Types and morphological features of hominid and carnivore bone surface damage

The utility of bone surface modifications depends wholly on our ability to link a taphonomic trace (e.g., a linear striation on a bone) to a taphonomic actor (e.g., a hominid using a stone tool to butcher a carcass). Therefore, identifying attributes that reliably and consistently distinguish between different types of taphonomic actors is of paramount importance. The best way to become familiar with the morphological features of surface modifications is to work with actualistic assemblages; in these situations, one can be sure that the process of mark creation was observed, and thus the taphonomic actor(s) is known unambiguously. Because excellent discussions of signature criteria for hominid and carnivore damage are already available (Blumenschine et al., 1996; Fisher, 1995), the next two sections provide only a brief summary of these attributes as revealed through actualistic studies.

Hominid damage

Hominid-imparted damage includes those marks created by either sharp- or blunt-edged stone tools (hominid tooth marks are discussed later). Stone tool cut marks (Figure 3.1) appear as fine, linear striations with V-shaped cross-sections that often possess parallel to subparallel microstriations both within and on the wall of the main groove (*shoulder effects*; Bunn, 1981; Potts and Shipman, 1981; Shipman and Rose, 1983). Some cut marks also preserve barbs, which are small hooks that occur at the heads and/or tails of cut marks that result from "small, inadvertent motions of the hand either in initiating or in terminating a stroke" (Shipman and Rose, 1983: 66).

   Percussion marks (Figure 3.2) result from the use of unmodified (simple cobbles) or modified (e.g., choppers or polyhedrons) hammerstones to breach the medullary cavities of long bones for fat-rich marrow. Classic percussion marks "occur as pits, grooves or isolated patches of microstriations" (Blumenschine, 1995: 29). Microstriations are found within and/or emanate from the percussion pit (Blumenschine and Selvaggio, 1988, 1991; Turner, 1983; White, 1992). In addition to classic percussion marks (pits with associated microstiations), analysts have also identified *striae fields*, which "are composed of extremely shallow, subparallel scratches that usually cover relatively expansive lengths of cortical surface, between 5 and >50mm" (Pickering and Egeland, 2006: 462; see also Turner, 1983;
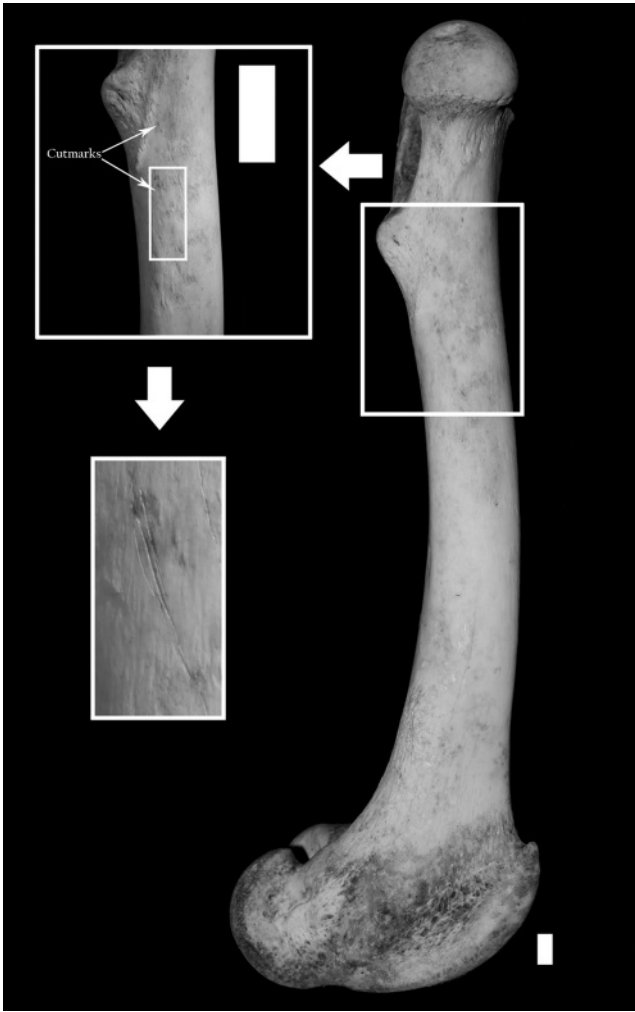
FIGURE 3.1. Medial view of the left femur of an elk (*Cervus elaphus*) showing stone tool cut marks. These cut marks were created during experimental butchery. Note the parallel to subparallel orientation, deep, V-shaped cross-section of the marks, and in the close-up, the multiple striations that are created within the grooves of the main marks. All scale bars = 1cm.

White, 1992). Experimental data show that striae fields are more often located on the surface of the bone in contact with the anvil (when one is used), rather than the surface that is impacted by the hammerstone (Pickering and Egeland, 2006). The microstriations so common to and diagnostic

of percussion marks are produced when the grains of a hammerstone scrape or abrade against the bone surface during impact; however, experimental work has demonstrated that percussion marks can also manifest themselves as pits without associated microstriations. Galán et al. (2009), for example, report that nearly one-third of the percussion marks created by unmodified hammerstones lack microstriations in their sample, and because of this, they cannot be distinguished morphologically from carnivore tooth marks. Overall, however, percussion pits with associated microstriations tend to be produced in the highest frequency in experimental assemblages, followed by striae fields and then pits without microstriations (Galán et al., 2009).

Carnivore damage

The morphological features of carnivore damage have been described in some detail by Binford (1981: 44–49), Blumenschine (1995: 29), Blumenschine and Marean (1993: 279–280), Blumenschine et al. (1996: 496), Fisher (1995), Haynes (1980), and Shipman (1983). Although there is interanalyst variability in terminology, four main categories of carnivore damage are generally recognized (Figure 3.3): furrowing, punctures, pits, and scores (Binford, 1981: 44). Furrowing is caused by sustained chewing of the soft cancellous regions of bones and is frequently manifest as partial or total destruction of bone portions, particularly the epiphyses of long bones. Crenulated edges (following Pickering and Wallis, 1997: 1118) are the final product of furrowing and can therefore be included in this category. Tooth punctures result from the bone collapsing under the tooth and are characterized by distinct holes in the cortical surface. Tooth pits are roughly circular in plan view whereas tooth scores are elongated (typically with a length three or more times greater than the width; Selvaggio, 1994) with U-shaped cross-sections. Both pits and scores commonly show internal crushing as a result of tooth-on-bone contact.

Several workers have correctly pointed out that it might not be safe to assume that all tooth marking can be attributed to carnivores, and hominids in particular must be considered as potential tooth-marking agents (Brain, 1967, 1969, 1981; Landt, 2007; Martínez, 2009; Pickering and Wallace, 1997; White and Toth, 2007). Unfortunately, there are currently no diagnostic criteria that appear to clearly differentiate human chewing damage from that of carnivores (although attempts are underway; Fernández-Jalvo and Andrews, 2011). One might expect to find more hominid chewing
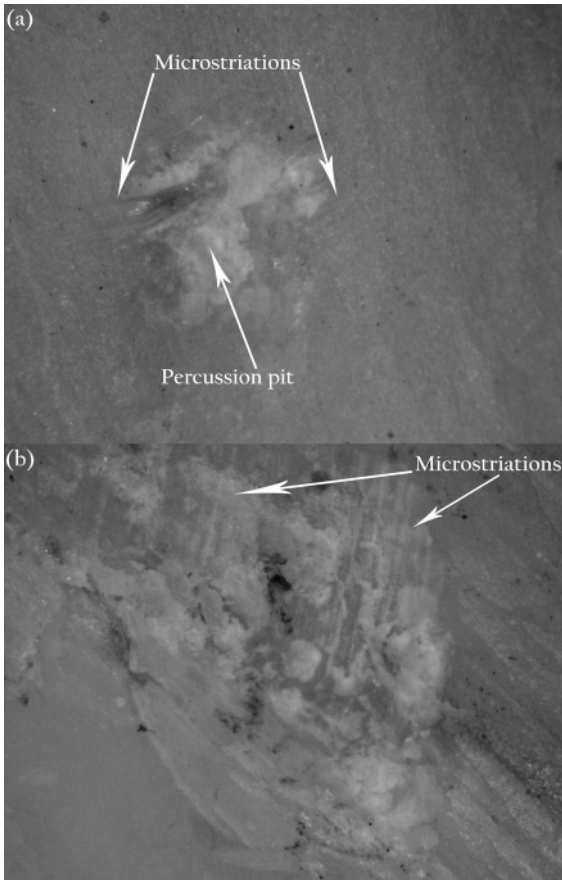
FIGURE 3.2. Examples of percussion marks. Note the microstriations emanating from the percussion pits. Photos courtesy of M. Domínguez-Rodrigo.

damage on smaller carcasses, as bones from larger carcasses would have more often been processed with stone tools rather than orally. Other non-carnivore agents that could be applicable to Oldowan sites for which tooth mark data exist include nonhuman primates, suids, crocodiles, and raptors (Andrews, 1990; Domínguez-Solera and Domínguez-Rodrigo, 2009; Njau and Blumenschine, 2006). Another class of bone surface modification that is relevant is digestive damage. Bones that have either been regurgitated after some time in the stomach or that have passed completely through the gastrointestinal tract of a carnivore (or hominid)

often show characteristic thinning and rounding (Lyman, 1994: 204–205, 210–211).

Tooth mark dimensions and identifying carnivore types

There is a growing body of research aimed at identifying species-specific patterns of bone modification among carnivores (Andrews, 1995; Andrews and Armour-Chelu, 1998; Andrews and Fernández-Jalvo, 1997; Delaney-Rivera et al., 2009; Domínguez-Rodrigo and Piqueras, 2003; Haynes 1983; Pickering et al., 2004a; Piqueras, 2002; Pobiner, 2007; Pobiner and Blumenschine, 2003; Selvaggio, 1994; Selvaggio and Wilder, 2001). There are two main reasons why information on the type or types of carnivores involved in assemblage formation is important. First, carnivores are very diverse in their level of sociality, and one can easily imagine that a gregarious species like the spotted hyena would have posed a different competitive dilemma for Oldowan hominids than, say, a relatively solitary species like the leopard. Second, differences in body size and dental armament furnish carnivores with a variety of carcass modification abilities, which in turn has an effect on the availability of carcass resources to other consumers, including hominids. These factors are even more important given the greater diversity of the large carnivore guild during Oldowan times relative to today (Werdelin and Lewis, 2005).

In terms of bone surface modifications, the underlying logic is very simple: larger carnivores have larger teeth, which in turn create larger tooth punctures, pits, or scores. Most analyses have used digital calipers to measure tooth mark dimensions from high-quality negative molds of bone surfaces. As long as only well-defined tooth marks are used and the outlines are clearly marked on the molds, this method provides reliable results. In some cases, however, the molding material can peel off some of the cortical surface, particularly in poorly preserved assemblages. Digital imaging techniques can circumvent this problem, and Delany-Rivera et al. (2009) describe a reliable method that uses digital photography and open-source imaging software.

Unfortunately, the relatively simple theoretical relationship described here has proved to be somewhat more complicated in practice. The most comprehensive datasets show that there is much overlap between carnivore species in the dimensions of tooth marks. For example, Domínguez-Rodrigo and Piqueras (2003) find that the length and breadth maxima of tooth pits created by cheetahs, leopards, lions, spotted hyenas, large dogs, and jackals on the dense cortical bone of limb bone diaphyses only reliably
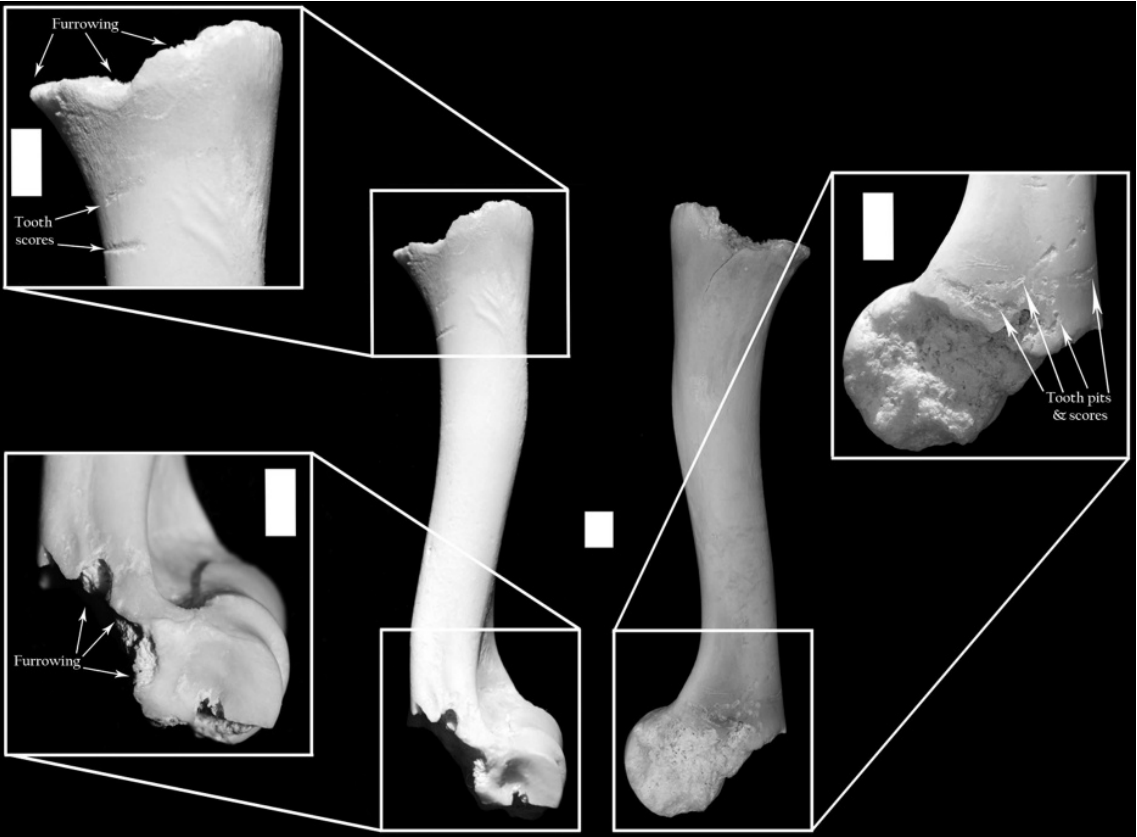
FIGURE 3.3. Medial (*right*) and lateral (*left*) views of the right humerus of a white-tailed deer (*Odocoileus virginianus*) showing various types of carnivore damage. This damage was created by a captive male mountain lion (*Puma concolor*). All scale bars = 1cm.

separate carnivores into two groups: those with less robust dentitions (e.g., cheetahs, leopards, and jackals) and those with more robust dentitions (e.g., large dogs, lions, and spotted hyenas). Although it is likely that the size of tooth marks alone will not identify the species of carnivore responsible for their creation, other taphonomic data, including carcass size, levels of bone destruction, and the frequencies and anatomical placement of tooth marks, can aid in more precisely identifying the carnivore(s) involved in the formation of Oldowan assemblages.

Protocol, problems, and pitfalls in the identification of bone surface modifications

Minimally, all surface mark identification in either actualistic or archaeological contexts should be carried out with a strong light source and the aid of at least 10× to 16× magnification under hand lenses or binocular microscopes. Using this methodology, Blumenschine et al. (1996) report that expert analysts accurately identify experimentally produced surface marks at rates of 99%, whereas novices with less than three hours' training with experimental controls achieve identification rates of 86%. Some researchers recommend the use of higher magnification (80×–750×), including scanning electron microscopy (SEM), for confident identifications of surface marks (e.g., Andrews and Cook, 1985; Olsen and Shipman, 1988). While such magnification might be warranted for the small number of ambiguous marks that invariably occur in any fossil assemblage, SEM analysis in particular is a time-consuming and relatively costly undertaking. Therefore, this method should be carried out only on subsamples of marks that lack distinctive morphologies when viewed under binocular microscopes or hand lenses.

As discussed previously, actualistic data clearly show that surface marks possess diagnostic morphologies, and further, that these morphologies are in most cases identifiable under relatively low magnifications. We must now confront one of the greatest challenges for Oldowan taphonomists: translating morphological criteria generated from actualistic assemblages of known derivation to fossil assemblages of unknown derivation. The reality is that, in the latter case, confident associations of surface marks with particular taphonomic actors are much less straightforward. The point here is that a familiarity with "pristine" actualistic assemblages of butchered and/or carnivore-ravaged bone is not enough; one must also take into account the myriad factors that can, in the case of the Oldowan, impact bone assemblages over one or two (or more) million years. A *configurational approach*

to surface mark identification therefore should be practiced, in which not only mark morphology but also the anatomical placement of the mark and the sedimentary context from which the specimen derives are taken into account (as recommended by researchers like Binford [1981], Bunn [1991], and Fisher [1995], and implemented by various researchers).

As an example of the importance of such an approach to surface mark identification, consider the Oldowan faunas from Member 3 at Swartkrans Cave (South Africa) and the site of DK in Bed I at Olduvai Gorge (Tanzania), which date to between 1.8 and 1.0 and about 1.8 million years ago, respectively. Both faunas are relatively well preserved and were excavated in association with stone tools. Ideally, an Oldowan taphonomist familiar with the morphological features of stone tool cut marks (based on actualistic assemblages) would identify prehistoric butchery damage on the bones and then proceed to reconstruct hominid subsistence at the sites. The issue is complicated, however, by the fact that the Swartkrans and DK bone surfaces have been affected by a variety of biotic and abiotic taphonomic processes typically not operant in modern actualistic assemblages. Manganese formation, soil leaching, water action, bacterial and fungal growth, subaerial weathering, and even glue from specimen curation are present in one or both assemblages, all of which complicate the identification of surface marks.

One of the more common processes at these (and other) Oldowan sites is sediment abrasion. Such damage results from trampling and/or fluvial transport and is known to manifest as fine, linear striations similar to stone tool cut marks. Based on actualistic samples, several researchers have summarized the morphological characteristics of sediment abrasion (Behrensmeyer et al., 1986, 1989; Fiorillo, 1989; Oliver, 1989; Olsen and Shipman, 1988). The most recent experimental work indicates that a multivariate approach can help to distinguish sediment abrasion from cut marks morphologically. When comparing marks created by (1) stone tool butchery and (2) pedestrian trampling generated by human subjects walking on bones embedded in various sedimentary substrates, Domínguez-Rodrigo et al. (2009) observe that only cut marks create grooves that are substantially deeper than they are wide, have microstriations located on the wall (as opposed to the base) of the groove, are straight (as opposed to sinuous) in trajectory, and show microstriations that are continuous along the entire groove. Recall, however, that a configurational approach involves other attributes in addition to mark morphology.

At Swartkrans, the karstic colluvium that makes up the cave fill from which the bones derive contains high frequencies of large, angular

(i.e., sharp) clasts, which hold great potential to create morphological cut mark mimics. This, coupled with the host of other taphonomic factors that had affected the cortical surfaces, encouraged Pickering et al. (2004b, 2007) to take a conservative approach to mark identification in their study of the Member 3 fauna. Importantly, the corroborating opinions of three analysts were required to accept a particular specimen as preserving cut marks (and/or any other sort of surface mark). While it is possible that some specimens that actually did preserve prehistoric cut marks were rejected as such, this is preferable to incorrect identifications. On the other hand, the DK fauna was excavated from a relatively fine-grained sedimentary matrix (as are most of the Bed I sites at Olduvai). There, sediment abrasion produced very superficial striae that contrast markedly with the deep grooves interpreted to have been inflicted by stone flakes. In addition, sediment abrasion resulted in randomly oriented striae that did not cluster near muscle attachments (Figure 3.4), which is different from the clusters of parallel to subparallel cut marks in the DK assemblage (Egeland, 2007a,b).

Quantification and analysis of bone surface modifications

There are several ways to quantify bone surface modifications (for useful summaries see Abe et al., 2002; Lyman, 1994: 303–306). The simplest method calculates the proportion of the total number of identified specimens (NISP) in any one category (e.g., femoral fragments, vertebral fragments, fragments from large animals) that preserve surface marks. Although probably the most commonly reported quantification method, researchers have cautioned that NISP-based data can be affected by differential fragmentation. Consider a simple example. Let us say that two bones, a humerus and a femur, were butchered by a hominid, and that all of the flesh was removed in the process. As a result, cut marks were created in several discrete clusters on the bone surfaces. Now, the still-hungry hominid decides to crack open both bones to get at the fat-rich marrow inside. This marrow extraction results in the creation of two humerus fragments and ten femur fragments. All else being equal, a NISP-based calculation will likely result in a lower cut-mark frequency for the femur (there are simply more fragments, the denominator) than for the humerus – even though both bones were butchered with the same intensity (i.e., until all of the flesh was removed). Although obviously a very simplified example, this potential shortcoming has led some researchers to suggest alternative methods of quantification. For example, Bartram (1993) argued that surface mark frequencies should also be counted as the proportion of complete bones
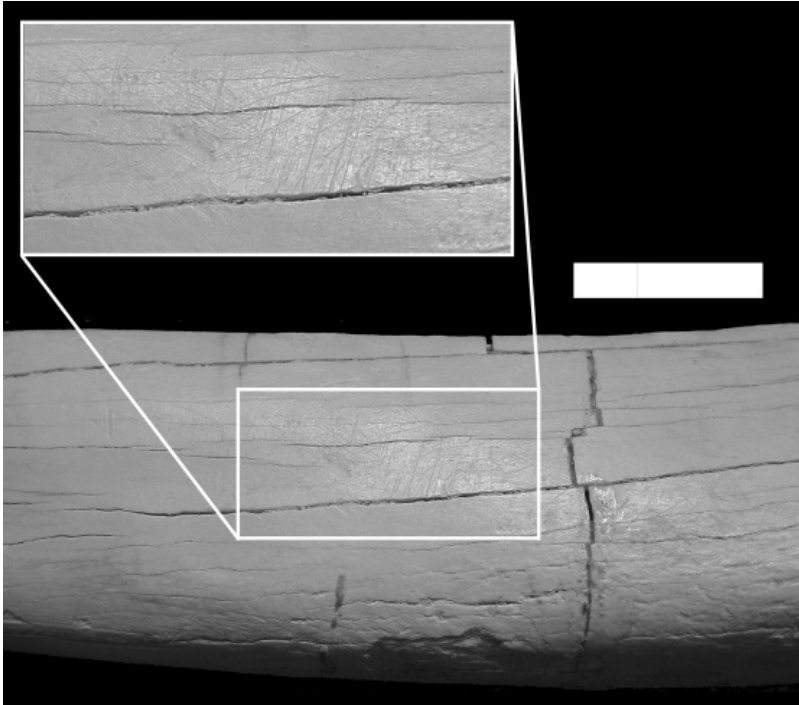
FIGURE 3.4. Tibia fragment from the site of DK in Bed I at Olduvai Gorge (ca. 1.8 million years old) showing sediment abrasion, probably caused by trampling. Note the shallow, randomly oriented striae (contrast with the stone tool cut marks in Figure 3.1). Scale bar = 1cm.

of any one element (as represented by the bone fragments and estimated by the minimum number of elements [MNE] count) that preserve surface marks. Others (Abe et al., 2002; Rapson, 1990) calculate surface mark frequencies relative to the surface area of the bone or bone fragment (a smaller bone or bone fragment is less likely to preserve a surface mark simply because it has less surface area). Another method of quantification that is seldom reported involves counts of individual marks on a specimen. The goal here is to count each spatially discrete mark that could have resulted from a single action (e.g., a cutting stroke, single hammerstone or anvil impact, and/or a tooth cusp coming into contact with a bone). Ideally, each cut-mark striation can be counted, although this is easier said than done when the striations are tightly clustered (Egeland, 2003). For percussion marks, each pit and its accompanying microstriae should be counted individually. Striae fields tend to be more diffuse and difficult to count, but Pickering and Egeland (2006) suggest that striae fields >5mm

apart should be considered distinct. Each discernable tooth pit, score, or puncture should be counted separately, although again this can be difficult or impossible on specimens with intense chewing damage.

The anatomical placement of surface modifications also provides vital information on carcass utilization by both hominids and carnivores. For example, cut marks on the midshafts of limb bones have been shown to reflect flesh removal, whereas those clustering near the epiphyses are most likely to be the result of dismemberment (Binford, 1981; Nilssen, 2000). Composite diagrams of surface marks (particularly cut marks) overlain on paper templates with multiple views of bones has been common practice among taphonomists for decades. It is now relatively easy to do this digitally with any number of image analysis software programs. For example, Adobe Photoshop (and other similar programs) allows users to create "layers," each of which could represent, for instance, the location of surface marks for a particular bone fragment. These layers can then be viewed and analyzed in any number of combinations depending on the analyst's needs. Abe et al. (2002) have developed a GIS-based add-on in ArcView that not only records digital drawings of surface marks but also performs several quantification functions as well. The one drawback of templates (digital or otherwise) is that the only fragments that can be included are (1) those that can be identified to skeletal element and (2) those that can be accurately oriented anatomically.

One method of tallying surface marks that circumvents the identifiability problem, at least for limb bones, is Blumenschine's (1988: 467) bone segment approach. In this system, limb bone fragments are divided into three categories: (1) epiphyseal specimens, which bear "all or a portion of the proximal or distal articular surface"; (2) near-epiphyseal specimens, which lack "any articular surfaces, but preserving cancellous tissue on the medullary surface that is indicative of proximity to an epiphysis"; and (3) midshaft specimens, which lack "articular surfaces and cancellous bone." Although Blumenschine's (1988) system is extremely successful at determining the order of carnivore access to carcasses (more on this later) its implementation has one potential shortcoming; namely its insensitivity to the *actual location* of a particular surface mark. For example, because most epiphyseal specimens as defined by Blumenschine (1988) include an attached portion of shaft, it is impossible to tell if a marked epiphyseal fragment actually bears marks on the articular surface or if the marks in fact occur on the attached shaft. Therefore, high frequencies of marked epiphyseal fragments could give the false impression that marks cluster near the joints when most actually occur on midshaft sections.

Bunn (2001: 209–210) and Domínguez-Rodrigo (1997: 674) therefore take a slightly different approach by tallying surface marks by bone sections. In this case, limb bones and limb bone fragments are divided into three anatomical sections: (1) proximal and distal epiphysis; (2) proximal and distal shaft; and (3) midshaft (note, however, that fragments must be identified as coming from, for example, the distal epiphysis of a particular limb bone). Therefore, a single specimen in Blumenschine's segment system might include one or more sections in the Bunn/Domínguez-Rodrigo system. Here, surface mark analysis tracks the actual location of marks, which can aid in determining the order of hominid access to carcasses and identifying the type(s) of carnivore responsible for carcass modification.

Actualistic samples and the timing of hominid and carnivore access to carcasses

The preceding has prepared us for an in-depth examination of a growing body of actualistic studies that provide data on the frequency and anatomical location of surface marks. The goal of these studies is to aid reconstructions of hominid butchery practices and to assess the timing of hominid and carnivore access to carcasses. Because limb bones tend to survive at high frequencies relative to other skeletal elements such as vertebrae and compact bones, actualistic studies have tended to focus on these bone types. Blumenschine's (1988) pioneering work in particular has fostered several studies that provide surface mark data on limb bone specimens. Three general scenarios are modeled by these studies. The first involves carcasses that are processed completely and exclusively by human experimenters (i.e., human- or hominid-only). In these experiments, bones are stripped of flesh with metal or stone knives and then cracked open to expose the marrow cavity. This produces limb bone assemblages with either cut marks or percussion marks, but obviously no carnivore tooth marks. The second scenario involves the defleshing of limb bones by various mammalian carnivores, followed by the fragmentation of the bones, mainly by hyenas (carnivore-only). The final scenario models the sequential utilization of carcasses in so-called dual- or multipatterned models (Blumenschine and Marean, 1993; Capaldo, 1995). The basic premise of dual-patterned studies is that a carcass processed by previous consumers "offers a carnivore [or hominid] a shortened menu of parts and a reduced nutrient yield compared to that available on a whole carcass" (Blumenschine and Marean, 1993: 275). These experimental actualistic data have been supplemented with ethnoarchaeological

studies of bone modification carried out among modern foraging groups such as the Hadza of Tanzania (Lupo and O'Connell, 2002).

Because the shaft portions of limb bones are more structurally dense than other parts (Lam et al., 1999), they tend to best survive the rigors of an assemblage's taphonomic history, particularly carnivore ravaging (Pickering et al., 2003). Therefore, midshaft fragments (*sensu* Blumenschine, 1988; see earlier) should provide the least-biased sample from which to calculate bone surface modifications. When carnivores have sole access to complete limb bones, they strip them of flesh and break them open to access marrow and grease, which results in well over 50% of midshaft fragments displaying tooth marks (Blumenschine, 1988, 1995; Capaldo, 1995, 1997; Selvaggio, 1998). In dual-patterned assemblages, in which hammerstone breakage and marrow extraction by humans is followed by carnivore (mainly hyena) ravaging, midshaft fragments are tooth marked at rates much lower than 50% (usually less than 20%; Blumenschine, 1988, 1995; Blumenschine and Marean, 1993; Capaldo, 1995, 1997). The explanation for this is very simple: hammerstone-broken midshafts no longer encase the nutrient-rich marrow cavity, which leaves scavenging carnivores little or no reason to tooth mark them. In dual-patterned assemblages where humans remove the flesh but leave the marrow cavities intact, midshaft tooth-mark frequencies remain high. The critical observation from these actualistic studies is that tooth-mark frequencies on midshafts provide a useful measure of the timing of carnivore access to within-bone nutrients; that is, did they get there before or after hominids broke the bones open for marrow?

As informative as tooth marks are in determining carnivore access to carcasses, they provide only indirect evidence on the carcass processing behavior of hominids. For direct evidence we must turn to butchery marks. Actualistic and ethnoarchaeological datasets indicate that when humans break open all bones in an assemblage to access marrow, percussion mark frequencies range from about 10% to 35% of midshaft NISP (Blumenschine and Selvaggio, 1988, 1991; Pickering and Egeland, 2006). When humans have primary access to flesh, cut-mark frequencies cluster around 5% to 40% of midshaft NISP (Bunn, 1982; Domínguez-Rodrigo, 1997, 1999b; Domínguez-Rodrigo and Barba, 2005; Lupo and O'Connell, 2002). Cut-mark frequencies in situations in which humans have secondary access to carcasses (removing scraps of flesh after carnivore consumption) are typically less than 10% of midshaft NISP (Domínguez-Rodrigo, 1997; Selvaggio, 1998). Other studies show, however, that there is no consistent relationship between the amount of flesh that is removed and cut-mark frequencies (Egeland, 2003; Pobiner and Braun, 2005b). The considerable variation

in and overlap of butchery mark values is due to several factors, including the size and taxon of the carcass, the intensity with which carcasses are butchered, tool raw material, and experimental protocols (Domínguez-Rodrigo, 2008; Domínguez-Rodrigo and Yravedra, 2008; Galán et al., 2009).

Oldowan taphonomists have attempted to solve this conundrum in several ways. Some have suggested that rather than lump all limb bone fragments together in the analysis, one should analyze them in a way that is sensitive to the amount of nutrients that they can provide to a potential consumer. Upper limb bones (femur/humerus) have substantial amounts of flesh and encase large reservoirs of marrow, whereas intermediate (tibia/radio-ulna) and lower limb bones (metapodials) have progressively less resources associated with them. Carnivores are also aware of this and in fact broadly follow this pattern in their consumption sequences (Blumenschine, 1986). It would logically follow, therefore, that when gaining access to carcasses before carnivores, hominids would butcher (and thus impart butchery marks on) those bones with the highest nutrient yields. Actualistic research does suggest that upper limb bones are cut marked at higher rates than are intermediate and lower limb bones when humans gain primary access to carcasses (Domínguez-Rodrigo, 1997; Domínguez-Rodrigo and Barba, 2005).

Actualistic work indicates further that the mere presence of cut marks on midshaft fragments may be meaningful in terms of hominid access. The argument goes like this: carnivores typically remove flesh from carcasses in a predictable sequence (Blumenschine, 1986), and if allowed to take their time, will usually leave little or no adhering flesh on midshaft sections of limb bones (Domínguez-Rodrigo, 1999a). So, if hominids were relegated to passively scavenging from picked-over carnivore kills, there would be no reason for them to impart cut marks on defleshed midshaft sections. Cut marks on limb bone midshafts (or any body part that is usually consumed early on by carnivores; for instance, rump flesh around the pelvis or viscera under the ribs) therefore would mean that a substantial amount of flesh was present when hominids butchered the carcass. Domínguez-Rodrigo and Barba (2007b) have taken this a step further by mapping the exact anatomical location of flesh scraps in a sample of twenty-eight carcasses consumed by lions in Kenya's Maasai Mara National Reserve. Those areas on limb bones that never preserved any flesh scraps were referred to as *hot zones* by these researchers (Domínguez-Rodrigo and Barba, 2007b: 90). They argue that if cut marks appear on hot zones, it is very unlikely that hominids accessed carcasses after they had been fully defleshed by felids (or other large carnivores). Other studies indicate that the amount of

flesh that remains after large carnivore consumption can vary considerably (Blumenschine, 1986; Pobiner, 2007; Selvaggio, 1994), which, as Pobiner (2008: 473) points out, is likely due to differences in ecological context. For example, all else being equal, one would expect that consumed carcasses found in areas with low carnivore density would retain more flesh than those found in areas with high carnivore density. Regardless, it has become clear that the anatomical placement of bone surface modifications is as important, if not more so, than the frequency of their occurrence (Pickering and Egeland, 2009).

Comparing surface mark frequencies between fossil and actualistic assemblages

The researchers who have conducted these actualistic studies have correctly stressed the importance of comparability between modern datasets and fossil assemblages (Blumenschine, 1995: 28, 33–39; Capaldo, 1997: 556–557; 1998: 312–314; Marean, 1991; Selvaggio, 1994: 194). There are two major issues here, the first of which concerns breakage. This is important because the amount of breakage controls how many fragments are created, and the number of fragments is the denominator in NISP-based counts of surface mark frequencies. Any process that creates additional fragments in fossil but not in actualistic assemblages therefore can artificially depress surface mark frequencies in the former relative to the latter. In fact, fossil assemblages are often exposed to just such processes. For example, while actualistic controls experience breakage related only to the extraction of carcass nutrients by humans and/or carnivores (referred to as *green breakage*), fossil assemblages can undergo additional breakage due to ancient diagenetic processes such as weathering or sediment compaction and/or recent breakage from excavation or curation damage. (Although a detailed discussion is beyond the scope of this chapter, there are established methods to determine when and how a bone was broken.) Of course, the only way to eliminate such bias completely would be to refit all the diagenetically and/or recently broken specimens. For various reasons, not the least of which is time constraints, this is rarely possible. Therefore, the most straightforward way of maximizing comparability is to exclude from comparative analyses the fossil specimens that show diagenetic and/or recent breakage, *even if they preserve prehistoric surface marks*. Pickering et al. (2007, 2008) offer an alternative method that allows the inclusion of specimens with diagenetic and/or recent breakage without the need for extensive refitting. They reason that because at least two fragments will be produced when a single specimen is broken, the number of diagenetically and/or recently

broken specimens can be divided by two and the resulting value added to the number of green-broken specimens. Although this does not completely eliminate the bias introduced by differential breakage, it can help make fossil assemblages more comparable with actualistic control samples.

The second issue involves cortical surface preservation. In actualistic assemblages, all bone cortices are more or less pristine, and therefore any analyst who knows what to look for should be able to identify all the marked specimens accurately. As one might well expect, this is not always the case in fossil assemblages: poor cortical surface preservation results from myriad factors and can obscure prehistoric surface marks. To realistically compare fossil bone modification data with those of actualistic controls, one would need to calculate surface mark percentages based only on that portion of the assemblage that displays cortical surfaces that are well preserved enough to maintain identifiable prehistoric marks. Of course, what constitutes well preserved is another matter. In his study of faunas from Bed II at Olduvai Gorge (dated to between about 1.7 and 1.2 million years ago), Monahan (1996) assesses the "readability" of bone surfaces in quartiles, where a specimen whose entire cortex is in pristine condition is coded as 100% readable; less well-preserved specimens are coded as 75% to 99%, 50% to 74%, and so forth. He then creates adjusted surface mark frequencies by multiplying the number of marked specimens by the percentage of specimens with >50% readability. Monahan (1996) and others (Egeland et al., 2004) used these adjusted values to make comparisons between the Bed II data and actualistic assemblages. Pobiner et al. (2008) use a similar scheme in their analysis of faunas from Okote Member sites at Koobi Fora, Kenya (dated to about 1.5 million years ago) but consider specimens >75% readable as well preserved. The upside of this approach is that it is very explicit about how specimens are chosen for comparative analysis. The problem is that surface marks often appear in isolated or very restricted areas of bone fragments, and so even a specimen that is 75% readable might have once had tooth marks on what is now the remaining 25% unreadable surface. In other words, we are assuming here that the readable surface of a fragment is representative of the entire cortical surface, which might or might not be the case. Pickering et al. (2007, 2008: 33) take a more qualitative approach by assigning a score of *poor*, *moderate*, or *good* to specimens from Swartkrans, which is meant to indicate "the relative 'fidelity' of current bone surfaces for continuing to preserve prehistoric bone surface modifications." In this system, only specimens with good preservation are included in comparative analyses. The drawback here, as Pickering et al. (2008: 33) admit, is the subjective nature of the scoring system: the analyst must make the call as to which specimens are deemed well preserved enough to merit an assessment of

good and thus inclusion in comparative analyses (see Thompson [2005] for a useful methodology in a non-Oldowan context).

Apart from these two major concerns, there is one, final consideration when making comparisons between fossil and actualistic assemblages. Many of the actualistic studies do not consider bone specimens that are <2 cm in maximum dimension. These specimens must therefore also be removed from the fossil sample, even if they preserve prehistoric surface modifications.

What have bone surface modifications taught us about the Oldowan?

The point of this chapter is to convey the importance of bone surface modifications to understanding the lifeways of Oldowan hominids. So, let us examine what we think we know with a good degree of certainty:

Hominids were using Oldowan stone tools to butcher animals for food. This is the most secure and will probably be the most lasting contribution of bone surface modifications to our understanding of the Oldowan. Although it was long assumed that the mere presence of stone tools was enough to demonstrate that the associated fossil bones were the remains of early hominid meals (e.g., Clark and Haynes, 1970; Leakey, 1971), it was not until the discovery of cut marks at Oldowan sites (Bunn, 1981; Bunn et al., 1980; Potts and Shipman, 1981) that this relationship was confirmed beyond any doubt. Percussion marks and other fracture features show that early artifacts were used as marrow-processing implements as well (Blumenschine, 1995; Bunn, 1981; Oliver, 1994). In fact, the site that boasts some of the earliest evidence in the world for the use of stone tools as butchery implements, Bouri in Ethiopia at about 2.5 million years ago, lacks stone tools entirely: confirmation of carcass processing comes solely from the butchery marks on the bones (de Heinzelin et al., 1999). Butchered bones have been discovered in association with the very earliest evidence for stone tool manufacture 2.6 million years ago at the site of Gona, also in Ethiopia (Domínguez-Rodrigo et al., 2005), which indicates that from its very inception, Oldowan technology was used, at least in part (see below), for processing carcasses.

Hominids were also using Oldowan stone tools for activities unrelated to carcass butchery. Bone surface modifications, or, in this case the lack thereof, also reveal that at many Oldowan sites stone tools were *not* being used to butcher the fossil bones that co-occur with them. This pattern is particularly pervasive in Bed I at Olduvai Gorge, where only the fauna from the 1.8 million-year-old Level 22 at the FLK locality (the *Zinjanthropus Floor*

or *FLK Zinj*) is demonstrably anthropogenic, even though stone tools occur at many of the other Bed I sites (Bunn et al., 2010; Domínguez-Rodrigo et al., 2007a, 2010b). For what then were the stone tools at these sites being used? Given the undeniable importance of plant foods in early hominid diets (Peters, 1987; Sept 1992), it is likely that resources like nuts and roots would have dictated when and where hominids chose to concentrate their tool-using activities at Olduvai (Peters and Blumenschine, 1995) and beyond (Sept, 2001). Recent analyses of the Bed I lithics support this contention (Díez-Martín et al., 2010; Mora and de la Torre, 2005).

The menu of Oldowan hominids was relatively diverse. Butchery marks have been documented on animals that range in size from hedgehogs to elephants. This demonstrates that Oldowan hominids were willing and able to acquire carcasses of animals that were in some cases significantly larger than themselves and certainly larger than those procured by any modern nonhuman primate (Boesch and Boesch, 1989; Stanford et al., 1994; Uehara, 1997; Uehara et al., 1992; Watts and Mitani, 2002). Butchery marks are also found on animals that have habitat preferences ranging from open grassland to dense woodland (Blumenschine and Pobiner, 2007). This indicates that Oldowan hominids exploited animals from a wide variety of habitats, a pattern that also contrasts markedly with what is seen among nonhuman primates.

Carnivores were involved, in some form or another, in the formation of nearly every Oldowan site. Although it is often overlooked that early pioneers of paleoanthropology in Africa acknowledged that carnivores might have played some role in the accumulation and/or dispersal of faunal remains at early archaeological sites (e.g., Leakey, 1971; Isaac, 1971), a fuller appreciation of this was gained only with the formal integration of taphonomy into paleoanthropology through the work of researchers like Brain (1967, 1969, 1981). The near ubiquity of carnivore involvement in the formation of Oldowan faunas is attested by the presence of carnivore tooth marks (in addition to other lines of evidence) at nearly every early site with decent bone preservation (granting, of course, that some of the tooth marks might have come from the hominids themselves). Therefore, the question in many cases is not "*Did* carnivores contribute to this bone assemblage?" but rather "*How* did carnivores contribute to this bone assemblage?"

Hominids and carnivores overlapped in their use of space and, in some cases, overlapped in their use of individual carcasses. The co-occurrence of stone tools and/or butchered bones with fossils that bear carnivore tooth marks shows that hominids and carnivores used the same areas on the landscape during Oldowan times. The temporal dimension of this association

is less clear, however: that is to say, were hominids and carnivores on site at the same time, or was the overlap in space separated by months, years, or even decades? The answer for both questions seems to be *yes*. For example, there are sites such as FLK North in Bed I Olduvai (approximately 1.7 million years old) where hominid tool-using activities and carnivore carcass consumption appear to have been carried out in largely independent and unrelated episodes, separated by at least months if not longer (Bunn et al., 2010; Domínguez-Rodrigo and Barba, 2007a; Domínguez-Rodrigo et al., 2010a). At this and other Oldowan sites, however, there are examples of the co-occurrence of hominid and carnivore surface modifications on the same bone specimen. Because soft tissue remains nutritionally attractive for only a limited amount of time, this strongly suggests the sequential use of the same individual carcasses by hominids and carnivores likely within days (or less) of each other. This of course does not necessarily mean that hominids and carnivores were vying with each other for control of carcasses in dramatic competitive interactions (although this might have occurred sometimes). For instance, Isaac (1983: 9; see also Binford, 1983; Isaac and Crader, 1981), in his "common amenity" model, suggested that water, food, and other amenities probably drew hominids and carnivores to the same locations, in many cases independently, over many years.

In many cases, hominids enjoyed early access to carcasses. Perhaps no debate has sparked as much controversy as that over the carcass acquisition strategies of Oldowan hominids. Were they active hunters that could monopolize carcasses or timid scavengers relegated to picked-over carnivore kills? As with most debates, such a dichotomy grossly oversimplifies the complexity of the topic. Nevertheless, let us briefly dichotomize here before returning to a more realistic interpretation in a later section. Bunn (1981, 1982, 2001, 2007; Bunn and Ezzo, 1993; Bunn and Kroll, 1986) has argued consistently over the years that the frequency and anatomical location of cutmarks clearly indicate that Oldowan hominids were butchering fully fleshed carcasses. This implies that hominids were getting to carcasses before carnivores could consume them. Blumenschine (1995) and others (Capaldo, 1997; Selvaggio, 1998), based mainly on tooth mark and percussion mark data, contend that hominids scavenged felid-killed prey that they subsequently harvested for the remaining flesh scraps, bone marrow, and brain. Binford (1981; Binford et al., 1988) went even further and suggested that hominids were limited solely to heavily ravaged carcasses that provided nothing more than some marrow and perhaps bits of flesh. It is of note that Oldowan taphonomists have roundly rejected Binford's claims because he paid little heed to the bone surface modification data,

which has since contradicted his *marginal scavenger* hypothesis. Although the previously mentioned arguments have been based mainly (although not exclusively) on the evidence from the large and well-preserved FLK Zinj assemblage, steadily accumulating evidence from other Oldowan sites over the past 25 years or so has largely confirmed Bunn's original argument (Domínguez-Rodrigo, 2002; Domínguez-Rodrigo et al., 2002, 2007a; Egeland and Domínguez-Rodrigo, 2008; Ferraro, 2007; Pickering et al., 2004b, 2007, 2008; Pobiner et al., 2008). The general pattern that is emerging involves (1) cut marks on the midshafts of long bones, and more specifically on hot zones; and (2) low tooth-mark frequencies and high percussion mark frequencies on midshaft fragments. These two factors indicate that hominids were gaining access to and butchering fully fleshed carcasses and then breaking open long bones to access marrow. In most cases, carnivores later scavenged the bone refuse.

Where do we go from here?

Now let us examine some issues that need to be worked out: *OK, Oldowan hominids were eating large animals, but how important were meat and other animal products in their diets?* There is no question that Oldowan hominids exploited animals in ways unknown among other members of the Primate order, and it is probably not a coincidence that the earliest evidence for this exploitation coincides with the earliest stone tool technologies. To gauge how significant this dietary shift was for hominid biology and behavior, however, we must be able to say not only that hominids were getting ahold of carcasses but *how often* they were doing so. If Oldowan hominids were accessing carcasses on a regular basis, it is possible that a higher-quality diet based on easy-to-digest animal protein and fat could have fueled changes in brain size, modifications to life history, and expansions in range size (Aiello and Wells, 2002; Antón et al., 2002; Kaplan et al., 2000; Leonard et al., 2007). If so, Bunn's (2007) assertion that "meat made us human" may not be far off the mark.

Although there are several lines of evidence that can and should be used to examine this idea, butchery marks are the most critical because they alone document unambiguously the processing of carcasses by early hominids. We already know from butchery mark data that hominids in many cases were able to gain early access to carcasses, although this does not necessarily mean that animal products were integral components of their diets. What about the number of Oldowan sites that show evidence of butchery? Of the seventy-nine Oldowan assemblages from Africa that

have preserved faunal material, thirty-one, or about 39% of them, preserve butchery marks of some sort (Pobiner, 2007: tables 8.1 and 8.2).[1] Given that the faunas from some of those sites that lack butchery evidence suffer from poor cortical preservation, it is likely that this number is actually higher. Butchery evidence is rare at Oldowan sites outside of Africa, although this is likely to change as the sample of sites of this age increases (e.g., Martínez et al., 2010). This suggests that carnivory was a temporally and spatially widespread behavior, at least among Oldowan populations in Africa.

Another way to look at this problem is to determine the actual number of mammal carcasses that were butchered by hominids at Oldowan sites. Data on the minimum number of individuals (MNI) that were butchered are available from only a few sites. Two of the Olduvai sites show relatively high frequencies of butchered animals: FLK Zinj has the most, with a butchered MNI of eighteen (Domínguez-Rodrigo and Barba, 2007b), whereas at BK there is evidence of at least eleven butchered carcasses (Egeland and Domínguez-Rodrigo, 2008), although new excavations at the site will raise this total (Domínguez-Rodrigo et al., 2009). Pobiner (2007) reports butchered mammal MNIs of between nine and eleven at three 1.5-million-year-old Okote Member sites from Koobi Fora. These numbers actually compare quite favorably to those observed among modern hunter-gatherer camps (Bartram, 1993; Bunn et al., 1988; O'Connell et al., 1988a). However, we know that modern camp refuse represents usually less than a year of occupation, whereas the formation times of the Oldowan sites must be inferred. One can see, for example, how different the carcass acquisition rates at FLK Zinj would be if the assemblage formed over the course of no more than three years, as Bunn and Kroll (1987) have argued, relative to what they would be it had taken a decade or more to accumulate (Potts, 1986). The same issue must be worked out at other Oldowan sites as well.

OK, Oldowan hominids were gaining early access to carcasses in most cases, but were they actually hunting? The hunting prowess of Oldowan hominids really hits at the core of their humanity, because many think that proficient hunting of larger mammals (i.e., weighing more than about twenty or thirty pounds) indicates a more human-like adaptation. To discern active hunting from other forms of early carcass access such as mass deaths (e.g., mass drowning; Capaldo and Peters, 1995, 1996; but see Domínguez-Rodrigo et al., 2010b) or *power scavenging* (i.e., aggressively driving

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[1] Pobiner (2007) lists 77 assemblages with 29 preserving butchery marks. Subsequent to her summary, butchery marks have been identified at two additional sites/levels: FLK North Level 4 (Domínguez-Rodrigo et al., 2007b) and Swartkrans Members 1 and 2 (Pickering et al., 2008) for a total of 79 total assemblages with 31 preserving butchery marks.

carnivores off kills; *sensu* Bunn, 1996: 322) is extremely difficult to do with bone surface modifications. To demonstrate this unequivocally with surface mark data, one would need to identify impact marks created by projectiles (Letourneux and Petillon, 2008; Smith et al., 2007). Without this sort of evidence, which is currently lacking for the Oldowan, we are forced to speculate a bit. Bunn (e.g., 2007: 198) favors hunting for the acquisition of smaller animals, because lions and hyenas can consume such carcasses very quickly, and advocates power scavenging as the most likely acquisition strategy for medium-sized animals. Domínguez-Rodrigo and Barba (2006) point out that the ability of modern hunter-gatherers like the Hadza to drive predators off kills is based largely on their use of heavy bows (which are effective up to 40 meters). Given the lack of bow technology during the Oldowan, they therefore argue that confrontational scavenging would have been too dangerous an undertaking. This, in their opinion, leaves active hunting as the most likely alternative. Although no unambiguous hunting implements are preserved at Oldowan sites, Domínguez-Rodrigo et al. (2001: 298) have suggested that evidence for woodworking at Peninj, a 1.5 million-year-old site in Tanzania, might indicate the production of rudimentary spears. Is this all to say that Oldowan hominids never passively scavenged carcasses? Of course not; they certainly did when the opportunity presented itself, and in fact modern hunter-gatherers are always on the look-out for scavengeable carcasses (O'Connell et al., 1988b). Bunn and Ezzo (1993: 388) probably put it best when they state that hominids used a "flexible and sophisticated strategy of carcass acquisition that involved as the dominant methods active, confrontational scavenging to acquire large animals and both active scavenging and opportunistic hunting to acquire small animals. As part of this flexible, broadly based strategy, passive scavenging probably did occur, but not enough for it to be reflected as a significant, dominant factor in the known archaeological record."

Conclusion

The take-home messages from this chapter should be

1. As long as we can identify them correctly, bone surface modifications represent an unambiguous link between a carcass and whatever interacted with that carcass (in our case, hominids and carnivores).
2. Bone surface modifications are absolutely critical to any discussion of the formation of a bone assemblage, and thus to any broader discussion of Oldowan hominid behavior.

3. Familiarity with the diagnostic features of surface marks should be gained through the study of actualistic assemblages of known derivation. These morphological features cannot be applied uncritically to fossil assemblages that have experienced complex taphonomic histories, however. Therefore, a configurational approach to mark identification should always be practiced.

4. Fossil samples must be corrected to account for poor surface preservation and/or differential breakage before they are compared with modern actualistic assemblages.

5. Both the frequency occurrence and anatomical patterning of surface modifications are important factors to consider in determinations of hominid and carnivore access to carcasses.

6. Surface marks have taught us quite a bit about the lifeways of Oldowan hominids. We now know, for example, that (1) hominids used Oldowan tools both to butcher animals and, most likely, to process plant resources; (2) hominids exploited a greater diversity of mammalian prey than any nonhuman primate; (3) carnivores were active in the creation of nearly every Oldowan bone assemblage; (4) hominids and carnivores used the same places on the landscape, and in some cases fed from exactly the same carcasses; and (5) hominids were capable of gaining early access to fully fleshed carcasses.

7. Other issues are a bit cloudier when it comes to the use of surface modification data. For instance, we cannot be sure just how important animal resources were in the diets of Oldowan hominids based solely on surface marks. As it currently stands, the issue of active hunting is also an open question (although conclusive evidence of such is potentially attainable through bone surface modifications).

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