Chapter 13
Avian Carnivore, Ungulate, and Effects on Bone

This chapter reviews the effects of other vertebrate actors that can affect archaeofaunal assemblages. In contrast to Lyman's (1994b) review of taphonomy, it does not attempt a treatment of all aspects of these actors' effects but rather focuses on those aspects of their behavior most likely to impact archaeofaunal assemblages. It begins with avian carnivores, enumerating their bone damaging and reducing abilities, most common bone surface modifications, roles as bone accumulators, and potential for paleoenvironmental information. It then reviews similar traits of herbivores, both hoofed animals and rodents, emphasizing what motivates these taxa to modify or accumulate bones.

13.1 Avian Effects on Bone

Birds that modify bones include the avian raptors: hawks, falcons, eagles, buzzards, vultures, owls, plus tropical taxa such as bustards and other terrestrially adapted birds of prey. The most frequently consumed raptor prey are microfauna, defined by Andrews (1990) as mammals, birds, reptiles, and amphibians less than 5 kg in body weight. Within this, common prey species are rodents and insectivores; eagles may regularly take lagomorphs and the young of larger mammal species. Vultures and other avian scavengers often consume carcasses of much larger animals.

Archaeologists seeking to tease out human subsistence practices in such areas as arid North American West knew that ethnographic accounts testified to an overlap in prey taken by humans and by raptors, especially rabbits, hares, and larger rodents. Remains of such animals in caves and rock shelters where raptors may have roosted, even when spatially associated with artifacts, present a problem: were these the debris of human meals, or of raptors that occupied the same space, either sequentially or simultaneously? Practically speaking, can human consumption of these prey species be distinguished from that of raptors, from bone surface modifications

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or skeletal element representation? These questions guided much actualistic research into raptor effects on vertebrate remains by zooarchaeologists.

Likewise, paleontologists long recognized the potential of predatory birds' microfaunal accumulations for reconstructing paleoenvironments. The central question was whether raptor-accumulated microfaunal samples reflect an essentially random sample of microfaunal taxa around a raptor roost, or are they more idiosyncratic, species- or individual-specific, and hence less representative of paleoenvironments? Even earlier than did zooarchaeologists, paleontologists turned to actualistic research to explore this question.

Systematic taphonomic studies of avian effects on the remains of vertebrate prey or scavenged animals developed to answer both these questions. Detailed studies now indicate the distinctive impacts avian carnivores have on prey bones. This section summarizes the relevant literature on avian modifications to bone and on avian sampling of microfauna, with an eye toward these two issues.

Avian raptors cause three kinds of alteration to skeletal elements of vertebrate bodies they consume:

1. Bone surface modifications inflicted by the beak or by the talons during killing and eating. Damage reflects breaching the braincase and tearing body segments and flesh with beaks, as well as gripping prey during the kill and feeding with talons.
2. Destruction of skeletal elements or parts of them by stomach acids, the degree of destruction varying with taxon, owls being less likely to completely dissolve bones than are falcons, hawks, eagles, and vultures.
3. Transport of skeletal elements from the acquisition site to roosts or nests for further consumption or provisioning the young, accumulating bone debris at those places.

As with mammals, the extent of damage to bones results from interaction of the consumer's strength (usually correlated with body size) relative to the strength of the bones of the consumed (again, usually correlated with body size). Raptors can exert extraordinary levels of force relative to body weight, as some examples will show.

13.1.1 Consumption-Related Bone Breakage and Destruction

Owls usually hunt in the early morning, late evening, or night. Their prey are usually small relative to their own body size, and owls tend to swallow them whole, or to detach the head and then swallow the head and the postcranial body as two units (Andrews 1990). They later vomit up bones and bone fragments embedded in fur or feather pellets, which shield their digestive tracts from injury. Owls generally inflict less breakage on postcranial elements during consumption than do other raptors, though Andrews (1990:51) reports that certain owl species may produce considerable damage to elements. In most cases, they breach the braincase, as they usually kill prey by a bite to the back of the skull, and consume the brain early in feeding.

Even within one well-studied owl species, variability exists in the degree of bone damage. Saavedra and Simonetti (1998) compared three Chilean barn owl (*Tyto alba*) samples with five North American barn owl samples documented by others. They noted differing element frequencies and degrees of fragmentation across all samples and found significant divergences between the Chilean and North American samples, as well as within the South American samples. Kusmer (1990) offered a comparative discussion of taphonomic processes affecting prey remains consumed by owls. She cautions that, although owls usually inflict less damage than do other raptors, size matters. Smaller owl species and the young of larger species tear off parts of the body before swallowing, in the process breaking skeletal elements of prey more than do larger owls, who can swallow them whole. De Cupere et al. (2009) reported differences in processing depending upon whether female owls are rearing unfledged young, when the mother dismembers prey to a greater degree to feed her chicks than she would feeding herself. This produces greater degrees of skeletal damage in nesting sites assemblages than at roosts.

Diurnal raptors such as eagles, hawks, and falcons often take prey closer to their own body size, which require handling before consumption. These raptors break down bodies into segments and tear flesh from bones before swallowing them. Like owls, they regurgitate undigested parts in pellets. While diurnal raptors break cranial and postcranial elements more often than owls, their fragmentation rates seldom approach those of mammalian carnivores processing similar vertebrates (Andrews 1990:50–58). Avian raptor pellets have a different morphology in fossil form than do small mammal scats, and their bony contents tend to be considerably more complete (Andrews 1990:28; Mellet 1974); Schmitt and Juell (1994); (Schmitt 1995).

Andrews (1990) reviewed actualistic data on avian and mammalian carnivore modifications to microfauna, and Bochenski (2005) discusses actualistic findings on imperial eagle, golden eagle, tawny owl, eagle owl, long-eared owl, peregrine, and gyrfalcon prey element frequencies and modifications, specifying the rates of accumulation of axial versus limb elements, wing versus leg, amounts of digestion, etc., with useful tables. Lyman (1994a).

Eagles regularly take rabbits and hares, which are also human prey. Archaeological researchers on foragers in the Great Basin, USA have elucidated differences in assemblages produced by these actors. Hockett (1991, 1993) compared leporid remains from hawk, eagle, and owl roosts with those from archaeological sites. He reported that in eagle roost assemblages, crania, mandibles, humeri, and tibiae were present in relatively high frequencies, as Andrews (1990:51) found. Hockett's (1993) eagle roost analysis revealed feeding-related damage on leporid femora and tibiae; the large muscles attached to these elements may encourage more intensive handling. Hockett (1993) also reported that eagles produced diaphyseal cylinders on leporid tibiae similar to those found in archaeological sites, but that the eagle-processed cylinders were generally longer than those from human meals. However, he cautioned that raptor-processed tibiae resembled the first step in Great Basin foragers' bone bead production: removal of epiphyses via transverse fractures. He advocated further comparative work to sort out consistent indicators of one actor or the other. Schmitt (1995) examined leporid bones at two golden eagle (*Aquila chrysaetos*) roosts in the Great Basin, comparing element frequencies to Hockett's barn owl samples and to coyote scats. He found that hind limb elements were the commonest bones in the eagle samples, significantly diverging from patterns of representation in other avian and mammalian carnivores. He suggested eagles' handling of hind limbs conserves the elements in identifiable form, whereas consumption by coyotes does not.

13.1.2 Effects of Beaks and Talons

Hawks and eagles can inflict surface modifications on the bones of very small to medium sized animals. Lagomorphs have been the focus of special interest because of the use of rabbits and hares by raptors and humans. Several researchers have attempted to specify distinctive signatures of talons and beaks. Punctures to the cranium, probably associated with the killing bite, and to the innominates, associated with seizing and pinning the prey during the kill, are reported. Beaks also inflict notches along the margins of flat or previously broken bones. Hockett (1993:672) noted that avian punctures and notches lack opposing marks, unlike mammal tooth marks (Chap. 12). Andrews (1990) and Schmitt (1995:248) note that fractures produced by raptors were not associated with distinctive surface modifications. All three authors reported that punctures were relatively rare on mammalian prey. Bochenski et al. (2009) report considerable puncture damage inflicted during consumption by two European eagle species on the bones of large avian prey (Fig. 13.1). Such differences may reflect avian bones' greater delicacy and divergences in bird from mammal anatomy.

Berger and colleagues (Berger and Clarke 1995; Berger and McGraw 2007), analyzed modifications to fauna associated with the *Australopithecus africanus* juvenile from Taung, South Africa, and inferred avian involvement in the accumulation. Three species of modern African eagles regularly take antelopes up to 30 kg, the young of larger primates, and, very occasionally, small human children. Berger and colleagues studied fossils collected from a modern South Africa black eagle (*Aquila verreauxii*) nest, documenting taxa taken, element frequencies, and modifications. Assessing the non-hominin fossil sample recovered from the Taung deposits, they reported depressed fractures, punctures, notches, and scratches on small to medium vertebrates similar to those made by contemporary eagles (Fig. 13.2). These, the ubiquity of species taken by modern eagles, presence of very large eggshell fragments, and overall physical situation led investigators to infer that the Taung sample represents a large eagle nest. Berger and McGraw (2007) argue that the *Australopithecus* specimen itself displays punctures and scratching around the orbits similar to that on monkeys eaten by eagles and should also be considered eagle prey. While not disputing some raptor involvement at Taung, de Ruiter et al. (2010), question association of the Taung *Australopithecus* with other fossils recovered from an active lime works operation, as well as whether modifications on the specimen were perimortem.

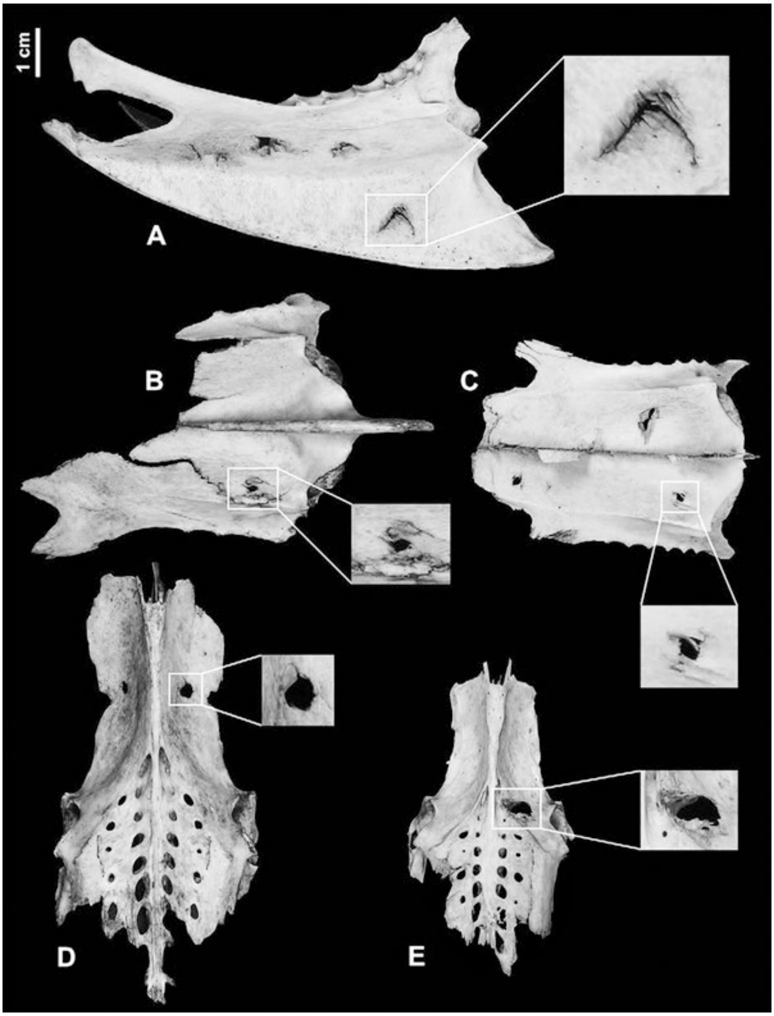

Fig. 13.1 Puncture marks made by white-tailed eagles on sternal and pelvic elements of large avian prey: **A.** nearly complete sternum of a meganser duck, with holes in corpus and crista sterni; **B.** anterior part of sternum of a meganser duck with a hole on the left side of body; **C.** nearly complete sternum of a duck, with several holes in body; **D.** pelvis of a goose, with holes in both preacetabular wings of each ilium; **E.** pelvis of a goose, with a hole above antitrochanter. (From Bochenski et al. (2009):126, Fig. 3, used with permission of the authors and Elsevier)

13.1.3 Raptor Stomach Acid Effects

Various taxonomic groups of raptors vary in stomach acidity levels, influencing their respective effects on swallowed bone. Acidity interacts with the size relations of predator to prey discussed above, and how commonly a species swallows whole

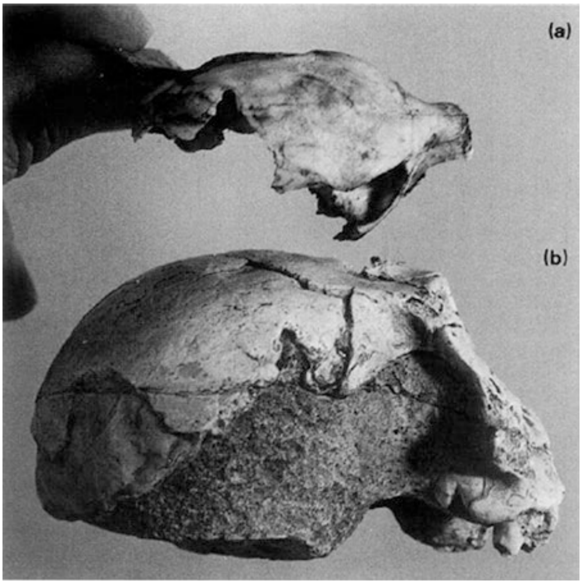

Fig. 13.2 V-shaped notches in the broken margin of (**a**) a modern hyrax cranium from a black eagle (*Aquila verreauxii*) nest and (**b**) a fossil baboon cranium from the Taung deposit. Notches are typical of beak punctures made along the edge of a skeletal element or on the edge of a break (From Berger and Clarke (1995):296, Fig. 12a and b, used with permission of the authors and Elsevier)

prey or skeletal elements. Owls have the least acid stomach environments, with pH 2.2–2.5, As a result, skeletal elements are best preserved in their pellets. Diurnal raptor stomach acids have pH of 1.2–1.8 (Andrews 1990; Dodson and Wexler 1979; Duke et al. 1976). For comparison, in giraffes and five other wild ruminant species, average pH in the abomasum section of the stomach is 3.6 (Bredin et al. 2008). Hawks' and eagles' regurgitated pellets contain fewer bones, and those present display more extreme pitting, erosion, and other acid-induced surface features than do bones regurgitated by owls (Mayhew 1977; Yalden and Yalden 1985). Nonetheless, captive owls have been shown to completely digest bones of some micromammals (Andrews 1990; Raczynski and Ruprecht 1974).

Vultures have extraordinarily high concentrations of stomach-acid producing cells and can dissolve larger bones, benefiting from the grease and collagen digested from bone. Houston and Copsey (1994) argued that, when carcasses are scarce, a bone diet may yield a higher caloric content than an equivalent weight of soft tissue. Margalida (2008:188) reported the bearded vulture (*Gypaetus barbatus*), weighing 4–6 kg, is the only vertebrate with a bone-dominated diet, consuming bones up to 28 cm by 4 cm. Its stomach acids can dissolve sheep-sized bones. Bearded vultures fracture bones by carrying them aloft and dropping them, and they stockpile bones at their nests for later consumption. Margalida (2008) demonstrated that these birds preferentially transport elements higher in white bone grease (oleic acid) content to their nests.

Skeletal elements with high surface-area-to-volume ratios, such as scapulae, innominates, and vertebrae, are most vulnerable to destruction by avian stomach acids, even by owls (Dodson and Wexler 1979; Andrews 1990). Actualistic research shows that acids consistently destroy carpals, tarsals, metapodials, and phalanges

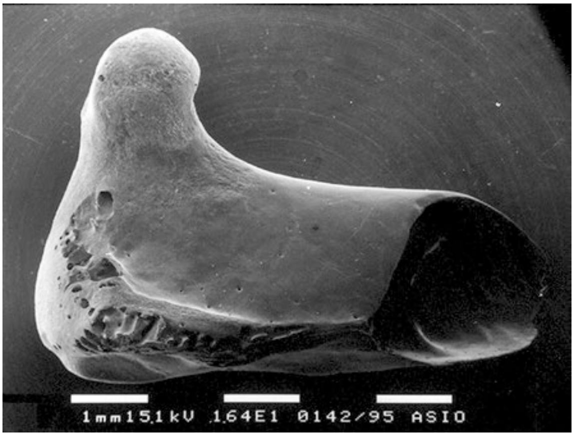

Fig. 13.3 SEM micrograph of acid-etched owl (*Asio*) femur, showing loss of cortical bone from trochanteric area and thinning of diaphyseal walls (Unpublished micrograph by Zbigniew M. Bochenski, used with permission of Z. Bochenski)

(Andrews 1990). The femur and tibia survive in relatively high frequencies. Maxillary and dentary regions of the skull, usually with their cheekteeth, are commonly preserved. Incisors and molars are among the last elements digested.

Bones that do survive to be regurgitated often display pits and fissuring etched by stomach acid, thinning or loss of cortical bone from epiphyses, thinning of diaphyses, and rounding of natural features and fracture surfaces (Fig. 13.3). Andrews (1990) illustrated the range of modifications typical of avian digestion, as did Fernández-Jalvo and Andrews (2016). Bochenski and Tomek (1997) discussed stomach acid erosion and delineate differences between this and bone surface erosion caused by soil pH.

Broughton et al. (2006) provided a case of barn owl (*Tyto alba*) predation on the tui chub (*Gila bicolor*), a fish species common in lakes of the North American Great Basin. They used a modern barn owl accumulation of fish bone from eastern Nevada as a dataset with which to compare a Terminal Pleistocene archaeofauna with the same species from Homestead Cave, Utah. They considered other actors in the Homestead Cave possibly responsible for the fish bone accumulation in their comparison, analyzing fish bone from modern coyote feces and that retrieved from human coprolites in Homestead Cave, also using notes on human digestive effects on fish bone (Butler and Schroeder 1998). Broughton et al. established that the Homestead Cave sample was in nearly all ways identical to the prey size parameters, element frequencies, and bone modifications of the barn owl fish bone sample and differed from actualistic samples of other actors. For Europe, Russ (2010) used comparative analyses of modern eagle owl pellets to assess whether this large raptor, known to accumulate bones of mammal prey in caves, would likely have accumulated fish bone as well. Although it is still possible some eagle owls accumulate fish bone, most modern samples yielded low frequencies of ichthyofaunal specimens. The author noted that further research is necessary.

13.1.4 Patterns of Raptorial Bone Accumulation

Raptors differ from mammalian carnivores in how they deposit bones of their prey. Pellets accumulate beneath habitual roosts, gradually releasing the bones as they dissociate and decay (Terry 2004). Andrews (1990:7–10) observed that raptors might trample older pellets and reduce delicate elements to fragments. Those that feed on larger prey and dismember and consume soft tissues often drop stripped bones below their roosts. Margalida's (2008) analysis of bearded vulture accumulations was noted above. Plug (1978), Mundy and Ledger (1976), and Richardson et al. (1986) studied bones around African vulture nests. These often bore traces of mammalian carnivore gnawing and were apparently scavenged from mammal kills by the vultures to provision their young. Richardson et al. (1986) reported that some such bones displayed acid alteration, reflecting on-site regurgitation by the vulturess.

Several researchers have assessed whether element frequencies or fracture rates alone can diagnose raptor agency and generally have found considerable diversity, even within species (e.g. Bochenski et al. 2009; Saavedra and Simonetti 1998). Commenting on the use of either element or fracture frequencies in diagnosing owls as agents, Kusmer (1990:636) stated:

> Although quantitative data may help to provide a short list of possible depositional agents, it may sometimes be more useful to approach the analysis from the angle of diagnostic marks (such as digestive erosion patterns) on individual bones and teeth. As always, multiple sources of evidence, including contextual and geological information, should be examined in conjunction… and form an important part of the taphonomic analysis of fossil assemblages.

Her generalization could well apply to all attempts to diagnose avian agency from fracture or element frequencies.

Terry (2007) revisited the question of determining the accumulating actor employing, principal component and discriminant function analyses on published micromammal datasets from raptor pellets (nocturnal and diurnal) and carnivore scats. She established that element fragmentation rates and the preservation of delicate versus sturdy elements could reliably distinguish nocturnal raptors (owl) samples from those produced by diurnal raptors and mammalian carnivores. However, diurnal raptors and mammalian carnivores could not reliably be distinguished one another by these or any other variables. Applying these actualistically-derived criteria to Grayson's (1998, 2000; see also Grayson 2011) data from the 12,000-year sequence at Homestead Cave, Utah, Terry (2007) established that owls were probably the dominant accumulators of microfauna throughout the Homestead sequence. She argued that this consistency in accumulating agents allows greater confidence in inferences about climate change from the shifts in micromammal species over time. The next sections discuss using raptor accumulations to infer paleoenvironment.

13.1.5 Raptors and Environmental Sampling

Earlier actualistic studies compared the diversity of microfaunal taxa trapped in a region with those represented in regional raptor pellets, concluding that raptor prey are *not* representative of a local community. Andrews (1990:28–29) discussed why this may be the case. First, some prey species are diurnal and others nocturnal, as are predator species; depending upon whether any given bones are accumulated by a diurnal or nocturnal raptor, one part of the circadian cycle will be sampled and the other neglected. Second, raptor species have prey size preferences, and species falling outside these ranges will seldom appear in their pellets. Third, through learned predatory behaviors, individual birds may develop even narrower prey species preferences. Andrews (1990:29) concluded that, although trapping-based species abundance and diversity data correlate well with general environmental type (e.g. high- versus low-productivity), it would be incautious to use data derived from raptor pellets to diagnose environmental type.

Other research supported these assertions. Hoffman (1988) notes that predatory behavior of some raptors may produce species structures entirely different from those in the environment. Brain (1981) compared species in modern barn owl pellets accumulating around two South African fossil localities with microfaunal taxa trapped in the two locales. He found that owls in the two areas diverged in species taken, and that neither prey profile was representative of the actual microfaunal community in their areas. Grayson (1981) and Andrews (1990) suggested treating pellet evidence as “presence or absence” data, rather than attempting statistical analyses of taxonomic abundance or diversity. In sum, the actualistic research suggested that, in the short term, no contemporary raptor samples of microfauna provides a representative sample of an environment’s microfauna, due to species- and even individual-specific prey selectivity.

However, paleontological and archaeological samples “compile” on a different temporal scale than is captured even by decades-long sampling programs. Acknowledging the limitations of actualistic-scale observations, Terry (2008) used modeling to explore whether the time averaging typical of paleontological assemblages might “smooth” such variability and produce taxonomic profiles that more accurately reflected community structure, and how much time such smoothing would require. Terry’s simplified model incorporated empirically derived data on multiple rodent species abundance cycles, which vary in frequencies and amplitude, and predator-prey interactions through such cycles. Terry’s (2008) results indicated that time averaging can smooth the swings in individual prey species abundances. A conservative estimate of the elapsed time needed to produce consistent taxonomic abundance estimates approaching those of the model life assemblage was around 140 years. Terry noted that this time span is roughly equivalent to that of the finest-grained time resolution of paleontological deposits. Thus, to use raptor accumulations for paleoenvironmental reconstructions effectively requires a more sophisticated approach, to overcome the “short attention spans” of actualistic studies although the longer-term of these contemporary studies may supply valuable information on frequency and amplitude of abundance cycles.

13.2 Ungulate Effects on Bones

Plant-eating vertebrates include the hoofed herbivores, or ungulates, and many rodent species. Both ungulates and rodents can modify and in some cases accumulate bones. Hoofed animals should further be divided between ruminant artiodactyls, a highly diverse taxonomic group with ruminating stomachs, and suids (pigs), artiodactyls with less specialized guts and in nearly all species a more omnivorous diet. Ruminants display great variability in crown heights but a common "plan" of interlocking premolars and molars with exposed enamel and dentine ridges on their occlusal surfaces that grate up leafy forage (Chap. 7). With a few African exceptions, pig species have omnivore diets and cheekteeth with rounded cusps. As a result of these differences, these two groups of artiodactyls mark bones differently and will be treated in separate sections below.

13.2.1 Ruminant Osteophagia

In environments poor in phosphorus, calcium, or sodium, each a necessary nutrient and bone component, ruminants often chew bones and antlers they encounter in the landscape to obtain these and other nutrients. Fresh or dry bones may be gnawed. Such bone recycling is called osteophagia, or pica. Osteophagia can completely destroy bones, or it can modify bone surfaces in ways that could be mistaken for carnivore gnawing or even human tool production. It has been documented from the early twentieth century from Africa (Theiler et al. 1924; Yellen 1977; Sekulic and Estes 1977), Europe (Sutcliffe 1976; Brothwell 1976; Kierdorf 1993), Arabia, and North America Sutcliffe (1973; Bowyer 1983) in camels, cattle, sheep, red deer/wapiti, giraffes, and various African antelopes.

Denton et al. (1986) explored the biochemical motivations of osteophagia through controlled experiments with heifers that had never before eaten bone, by lowering their blood serum phosphate levels and presenting them with bones along with similarly sized materials. With lowered blood serum phosphorus levels, the heifers quickly selected bones for chewing, apparently using olfactory cues, and engaged in "avid" chewing. They only stopped their gnawing a few hours after their blood phosphorus levels were returned to normal.

How ruminants absorb phosphorous from bits of masticated bone is unclear because of the ruminant digestive system's complexity. Forage passes from mouth to the reticulum to the rumen, where symbiotic bacteria ferment it. Then, it is regurgitated to be chewed again, then swallowed and further fermented in the rumen before passing to the omasum and finally to the abomasum, or true stomach, the only environment with acid-producing cells maintaining a low enough pH to dissolve bioapatite. Bredin et al. (2008) investigated the process of absorption, and readers seeking more information can consult that article. These authors note that saliva "softened" and produced "visible erosion" of cancellous bone, and opined

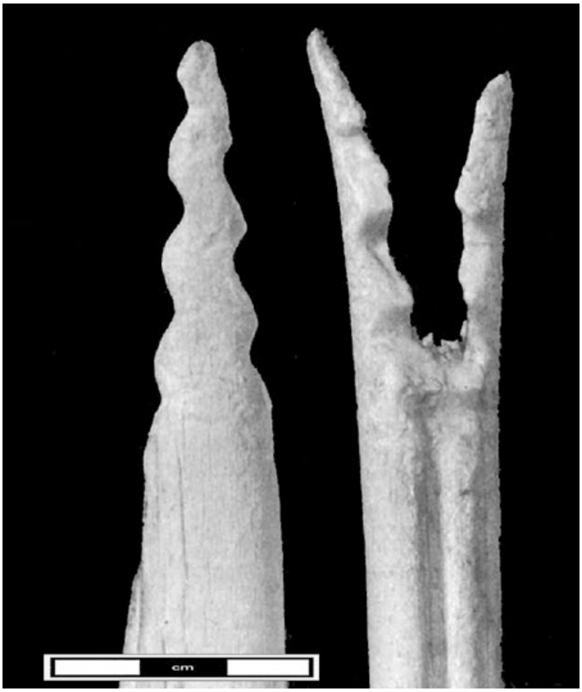

Fig. 13.4 Bones chewed by reindeer/caribou, showing the distinctive zigzag pattern of bone modifications produced by chewing the bones with the cheek teeth (From Sutcliffe 1973:Figs. 3 and 9, used with permission of Springer Publishing)

that saliva's effects may facilitate further mechanical breakdown of bone particles during rumination Bredin et al. (2008: 5–6).

Zooarchaeologists may encounter a range of osteophagia products. Sutcliffe (1973, 1976) described the process of dental modification by ruminants: they clamp bones between their premolars and molars in one side of the mouth, "like a cigar" (1973:429). Grinding their teeth against a length of bone scrapes bits of bone off the surface, leaving scars on opposing sides. With enough repetition, these actions produce zigzag profiles in gnawed long bones that, in their most extreme form, appear as "forks" or "prongs" on bone (Fig. 13.4). Brothwell (1976) noted that, depending on the original shape of the element, early stages of gnawing produce broad, flat marks, also reported and illustrated by Hutson et al. (2013) for skeletal elements chewed by giraffes and African antelopes. Both Hutson et al. (2013) and Cáceres et al. (2011) report and illustrate tooth scores oriented at right angles to the long axis of diaphyses (Figs. 13.5 and 13.6). Some modified diaphyses display what Hutson et al. (2013: Fig. 3) characterize as crushing or gouging. Both Hutson et al. (2013) and Cáceres et al. (2011) also report epiphyseal gnawing, leading to exposure of cancellous bone and its reduction into the "fork" shape with continued chewing, producing the pronged shape illustrated by Sutcliffe (Figs. 13.6).

Cáceres et al. (2011: Table 3) compared ruminant bone modifications to those of small to medium carnivores, and Hutson et al. (2013: Table 1) updated this for ruminant vs. large carnivore gnawing effects, using the same format. Both sets of researchers note that overlaps exists between herbivore and carnivore marks, but

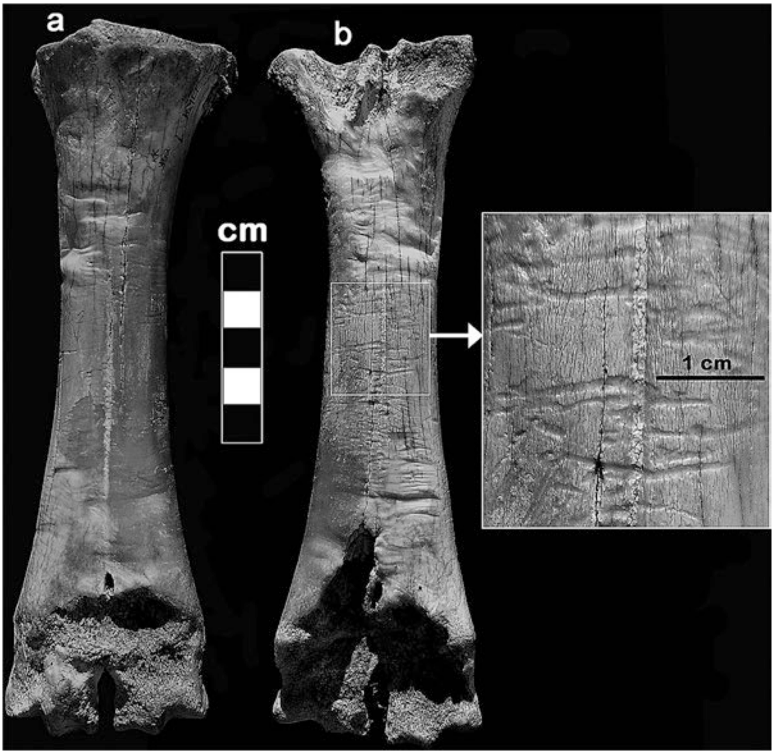

Fig. 13.5 Right ungulate-gnawed metacarpal of a bovid size class III (84–296 kg) antelope, from Kyle Recreational Park, Zimbabwe: **a** anterior view; **b** posterior view. Showing both horizontal scores to diaphysis made by cheekteeth and reduction of epiphyses (From Hutson et al. (2013):4142, Fig. 2. Used with permission of the authors and Elsevier)

some traits help sort out actor. Ruminants and carnivores both produce grooves and a form of scooping-out, but ruminants do not usually inflict pits or punctures along with these traces, nor does their scooping-out involve furrowing. Hutson et al. (2013: Fig. 9) illustrate comparative cases of giraffe, captive hyena, and wolf gnawing effects on the same element, a proximal tibia. These show carnivores' greater extent of compact and cancellous bone reduction (chipping back, scooping out).

13.2.2 Suid Gnawing of Bone

Most pigs are omnivores. Anecdotal reports of various wild species scavenging dead primates in brushy or forested environments, suggest they can completely consume the bones of small to medium-large animals (Galdikas 1978; Teleki 1973). Greenfield (1988) experimentally fed cattle and pig bones to domestic pigs. The pigs trampled bones to detach soft tissues, then gnawed smaller elements, and

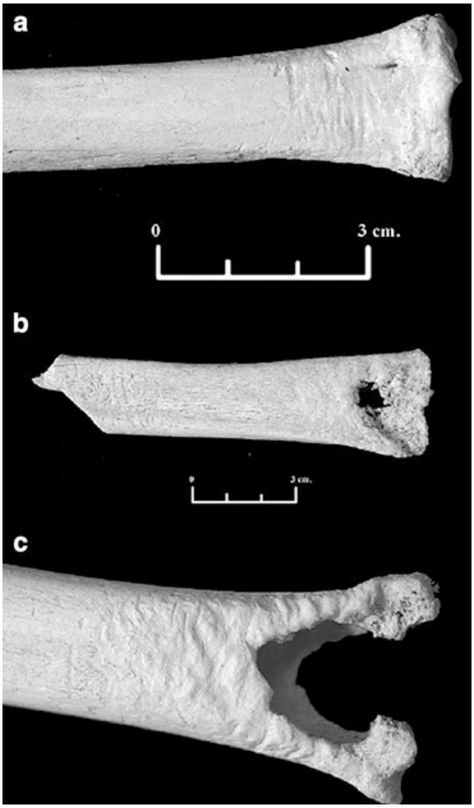

Fig. 13.6 Modification stages of herbivore-chewed bones. **a** Stage 1, transverse grooves inflicted on the proximal epiphysis. **b** Stage 2 (intermediate), cancellous bone is exposed and the epiphysis has started to disappear. **c** Stage 3, typical fork shape related to herbivore damage (From Cáceres et al. (2011):2769, Fig. 3, used with permission of the authors and Elsevier)

finally moved to long bones ends, showing disinterest in older, dry bones. They completely consumed suid bones and vertebrae of all sizes, while reducing but not destroying cattle long bones. Greenfield (1988:477) illustrated pig tooth marks on long bone epiphyses, reporting that some bones bore pits and others showed marks of the pigs' broad, shovel-like incisors.

Domínguez-Solera and Domínguez-Rodrigo (2009) did further experimental research on suid bone modification, feeding individual skeletal elements and carcass sections to free-ranging domestic Iberian pigs and wild boars (*Sus scrofa scrofa*). They laid out both unmodified bones and "dual-patterned" assemblages of long bones broken with hammerstones and the marrow removed (Chap. 12). Their findings supplement those of Greenfield in important ways:

1. Suids can destroy vertebrae and long bone epiphyses of sheep- and pig-sized animals and fragment their diaphyses. They modify cattle-sized bones, especially epiphyses.
2. Suids leave pits, scores, and furrowing on bone surfaces, but these modifications are inflicted primarily by their broad, flat incisors rather than by the cheek teeth and are generally shallower than those of canids.

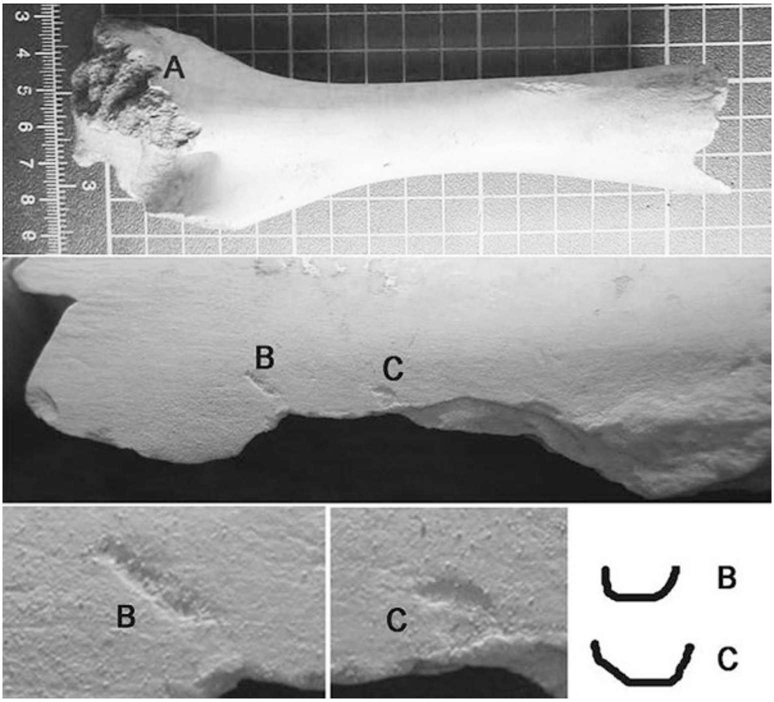

Fig. 13.7 **A.** Furrowing inflicted on epiphysis by pigs, showing the shallow and broad scars produced by incisors in cancellous tissues and **B., C.** tooth scores on compact bone (Domínguez-Solera and Domínguez-Rodrigo 2009:356, Fig. 9, used with permission of the authors and Elsevier)

3. In nearly half the experiments, tarsal bones of sheep- and pig-sized animals were consumed.
4. Unlike hyenas, pigs mouthed and licked diaphyseal shafts from which marrow had been removed, apparently seeking the last bits of adhering fat. In the process, they inflicted a considerable number of mid-shaft tooth marks (Fig. 13.7).

Zooarchaeologists working with archaeofaunas containing wild or domestic pigs should consider that scored, pitted, and furrowed specimens from larger animals could have been modified by suids rather than by true carnivores, attending closely to distinctive traits of the respective consumers' effects.

13.2.3 *Ungulate Trampling*

Hoofed animals can modify or break skeletal elements by treading on them. Skeletal elements are most likely to be damaged by trampling in high-traffic areas such as habitually used trails or waterhole margins (Behrensmeyer et al. 1989). If a

Fig. 13.8 Typical "wishbone fracture" behind mandibular symphysis on right dentary of a topi (*Damaliscus lunatus*), average body weight 118 kg. Death plus 2 years, Weathering Stage 2-3. East Lake Turkana, Kenya. Swiss Army Knife for scale is c. 5.7 cm (2.25 in) long. (Photo by the author)

substrate is of loose, sand- and gravel-size grains, treadage can deposit bones into the matrix, as it can in a moist, fine-grained matrix. If a fine-grained substrate is dry and hard, trampling can break the same elements. Types of damage produced by trampling include:

1. Fracture: some break forms, such as "wishbone" fractures of mandibles (Fig. 13.8), snapping in place to scapula blades, holes in weathered crania, etc., are characteristic of trampling. Others mimic breakage by other actors: spiral fractures, collapse of weathered long bone shafts, etc. (Figs. 13.9 and 13.10). Very large animals can crush entire elements (Fig. 13.11).
2. Polish: against finer substrates abrasion of bone surfaces appears as polished bone surfaces. Behrensmeyer et al. (1989) experimentally produced polishing in bones on game trails. Polishing may alter a patch of natural bone surface, a break surface, or a projection of an element (Fig. 15.5 shows an example of trampling abrasion).
3. Trample marks ("pseudo-cut marks"): V-shaped gouges with striated marks, resembling cut marks (Chap. 14) are usually developed on sand or gravel substrates. Shipman and Rose (1984) stated that "shouldering" effects may distinguish true cut marks from these marks. Lyman (1987) suggested that true cut marks should make anatomical sense in terms of disarticulation, defleshing, etc., and that trample marks are more randomly placed on convex bone surfaces. The next section reviews pseudo-cut marks in more detail.

Fig. 13.9 Collapse of a topi (*Damaliscus lunatus*) metacarpal along deep weathering cracks, in a disturbed area used by male topis for sparring during rutting season. Death plus 2 years, Weathering Stage 3. Swiss Army Knife for scale, is c. 5.7 cm (2.25 in) long. (Photo by the author)

Fig. 13.10 Splintering of a weathered radioulna of a common zebra (*Equus quagga boehmi*), weight 175–385 kg, caused by ungulate treadage near lake margin; fractures propagated along deep cracks created by columnar weathering into the medullary cavity. Death plus 6 years, Weathering Stage 4, East Lake Turkana, Kenya. Scale in 10 cm increments. (Photo by the author)

13.2.4 Trample Marks: Natural Mimics of the Stone Tool Edge

Some years after definition of SEM-derived criteria for stone tool cut marks to be described in Chap. 2, several researchers simultaneously noted marks on Miocene age bones that had the attributes of cut marks (Behrensmeyer et al. 1986, 1989; Fiorillo 1984, 1989). Since hominins had not yet appeared as a distinct lineage in the Miocene, "pseudo-cut marks" presented zooarchaeologists with a case of equifinality. To use Chap. 3's terminology, the effectors and actors creating cut marks and their natural mimics differ, one being a stone cutting edge in the hand of a hominin, the other being an angular grain of sand or gravel grating over a bone surface as an animal treads the bone against it. However, the actual causal process and context of production are similar: an irregularly shaped stone edge moving over a bone surface with enough force to produce a gouge. To ascertain what specific

Fig. 13.11 Trampling damage on a grand scale: crushed cranium of a topi (*Damaliscus lunatus*), average body weight 118 kg, in the bottom of a hippopotamus footprint in dried sediments near Lake Turkana's margin. Death plus 2 years, East Lake Turkana, Kenya (Photo by the author)

natural conditions produced “pseudo-cut marks,” (Behrensmeyer et al. 1989) and Fiorillo (1989) and, later, Olsen and Shipman (1988) experimentally monitored hoofed animals’ trampling effects on bones placed on various substrates. Experiments on sand and gravel substrates produced marks identical to those encountered in the fossil assemblages.

The problem was whether one could differentiate “pseudo-cut marks,” or, more accurately, trampling marks (Domínguez-Rodrigo et al. 2009), from those inflicted by stone tools. Olsen and Shipman (1988) proposed general criteria for trample marks:

1. They may be finer, shallower, and wider than stone tool cut marks.
2. Their placement on bones is “random,” in that they make less anatomical “sense” in terms of butchery than do true cut marks.
3. They may occur preferentially on convex surfaces.
4. They may be associated with development of polish on the bone.

However, Haynes (1991) noted that he found trampled, non-cut marked specimens from his elephant death study sites in Zimbabwe with each of the criteria proposed by Olsen and Shipman (1988) for true cut marks, and he called for more systematic research (see also Haynes and Krasinski 2010).

Domínguez-Rodrigo et al. (2009) published an experimentally based study aimed at distinguishing cut marks from trampling marks. They advocated developing, “the use of a low magnification approach (≤40×), which can enable the analysis of complete assemblages using either hand lenses or binocular lenses” (Domínguez-Rodrigo et al. 2009:2643), as SEM microscopy cannot. Their experimental procedures assessed the multiple and often mutually contradictory criteria for distinguishing cut marks from trampling marks in the literature, as well as whether their stated goal was possible.

The experiment monitored all variables previously noted in the literature, plus additional ones noted by members of the research team in other research contexts, totaling 16 in all (see Domínguez-Rodrigo et al. 2009: 2646–3647 for definitions of each). The study controlled for substrate (fine sand, medium grain sand, coarse sand, a mixture of all of these on a clay substrate, and gravel), duration of trampling, and elements trampled. The study also distinguished between cutmarks made by unretouched flakes and those made by retouched edges. Given the number of variables, the research employed multivariate analytic approaches to isolate the strongest correlations of effectors and effects perceptible at magnifications less than 40×.

The results indicated that marks made by trampling for longer than 2 min can by distinguished at magnifications less than 40× from cut marks using three of the 16 variables. This was true for cuts made by unretouched flakes and by retouched flakes. The authors cautioned that multiple criteria are essential because an overlap exists between trample marks and cut marks in each of these three individual traits.

For trample marks versus *unretouched* flake cut marks:

1. Seen from above, trample incisions in bone displayed more sinuous trajectories than do straighter-trajectory cut marks.
2. The cross-sectional shape of trample mark grooves are broader, with a _/ profile, while unretouched flake cut marks have a preponderance of V-shaped profiles.
3. Trample marks do not display the same shouldering and parallel grooves within the main mark that typical of cut marks (Chap. 14).

Domínguez-Rodrigo et al. repeat Behrensmeyer et al.'s (1986) caution that bones exposed to sustained trampling lose their microstriations through surface abrasion, so that the third trait may be unavailable in extensively trampled samples. To explore what the loss of striation features would mean for accuracy of distinctions between trample and cut marks, they ran a logistic regression analysis of the variables. This indicated that cross-sectional shape and trajectory alone could differentiate between trample marks and unretouched flake cut marks in 96.6% of their experimental sets.

Cut marks made by *retouched* edges often had _/ profiles similar to those of trample marks. However, Domínguez-Rodrigo et al. (2009: 2651) argued that multivariate analysis showed, trampling marks could be further differentiated from cut marks made with retouched flakes by the presence of shoulder effects and extensive flaking on the edge of the shoulder, as well as by the location of microstriations both at the base and on walls in the cut marks." Domínguez-Rodrigo et al. (2009: 2645) defined flaking as "a continuous series of exfoliation of the shoulder edge, which can occur on part of the trajectory of the shoulder or on most of it."

Domínguez-Rodrigo et al. (2009:2651) discuss distinguishing features for ambiguous pieces:

> Every single bone specimen subjected to trampling, irrespective of duration (10 s or 2 min), showed the typical microabrasion in the form of very shallow randomly distributed striae, which occupy various parts of the specimen. This microabrasion can only be properly identified with magnification (usually >10×).

They stipulate that these features were excluded from their experimental analysis because it is possible to find them both on trampled specimens and on ones that were cut marked and later trampled. This study offers a clearly defined template for replicative actualistic research on this topic.

Contextual analysis of archaeofaunal specimens' geological matrix and other inclusions – such as flaked stone debris – can facilitate evaluation of the likelihood of trampling-induced marks. Is the matrix sand or gravel, or is it too fine grained to have been the effector of the marks? If the matrix fine grained, are there some angular sedimentary particles in the deposit that could have made the marks? In my own work with East African pastoralist archaeofaunas, I see the presence of trample marks not as a distraction but as "part of the view" because high rates of these marks, in combination with abrasion on bone fracture and articular surfaces, suggest the action of hoofed animals within a settlement, hinting at space use and refuse disposal practices (Chap. 16 discusses abrasion).

13.2.5 Damage to Skeletal Elements During Life

Animals can suffer damage to their own skeletal elements in life, in the form of broken bones, tusks, and antlers, creating marks that may be confused with human modifications. Two types of modifications may be distinguished: traumatic injuries to skeletal elements through accidental fracture and subsequent bone pathology, and more common modifications of specific elements such as tusks and antlers during their use.

Haynes (1991:147–148) noted that, in the Hwange National Park, Zimbabwe, giraffe appeared especially liable to traumatic bone fracture. He illustrated fracture surfaces that became smooth through *in vivo* rubbing and abrasion. This kind of breakage would perfectly mimic fractures induced after death by other actors, and to date no research has been done to ascertain whether abrasion developed in this way differs from other forms of smoothing and polishing of bone break surfaces.

Modifications during life of a less traumatic nature occur on skeletal parts that directly confront the environment: teeth, horns, and antlers. Haynes (1991) noted that modern elephants routinely break tusk tips during scuffles over access to scarce water during drought years. These may mimic human polishing and flaking and very closely resemble objects alleged to be artifacts in several North American Paleoindian sites (Haynes 1991:Figs. 4.4 and 4.5).

S. L. Olsen (1989) studied unshed red deer antlers from 110 males and found the following types of damage to be common (Fig. 13.12):

1. Abrasion of the tines and parts of the beam, which could be confused with sedimentary abrasion.
2. Polishing of the tines and parts of the beam, which could be confused with abrasion caused by human use of antlers as tools.
3. Fractures at the tip of the beam, which might be mistaken for a broken point or awl tip made of antler.
4. Straight, shallow cuts on the beam ("marring"), which might be taken for cuts but lack the striations of cuts when seen under magnification.

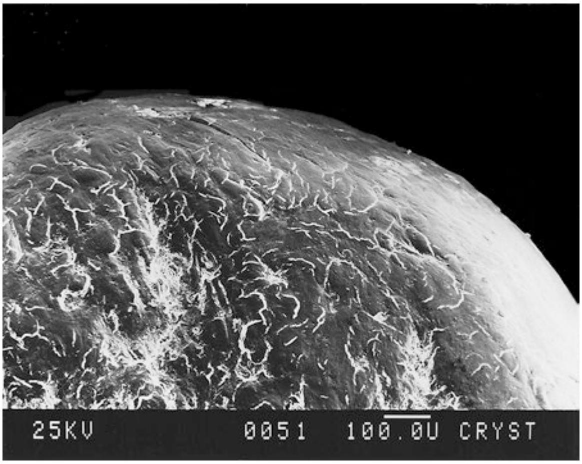

Fig. 13.12 SEM micrograph of natural polish and abrasion striations on deer antler tines, produced in life by a stag rubbing and thrashing his antlers against ground and vegetation. Scale bar 100 microns. See also Fig. 14.17 for antler percussor modification. (SEM micrograph by Sandra Olsen (1989:129 Fig. 2, used with permission of the author and Elsevier)

Olsen further investigated how to distinguish such modifications from similar ones that might develop postmortem if human use antlers as percussion tools. As illustrated in Fig. 14.17, Olsen's SEM study revealed some key differences to be discussed in Chap. 14.

13.3 Rodents as Bone Accumulators and Modifiers

Over their evolution, rodents have lost their lateral incisors and canines, retaining upper and lower first incisors that make distinctive marks on bone. In many rodent species, the incisors grow continuously, and rodents often gnaw on various objects, including bones. Some actually accumulate bones and other objects for gnawing. The need for minerals may motivate some such bone gnawing: captive Cape porcupines (*Hystrix africaeaustralis*) put on a low calcium diet directed twice as much gnawing to bones as did those on a higher-calcium regime. Zooarchaeologists should recognize the possible roles of rodent bone surface modification and accumulation of bones in forming an archaeofaunal sample.

Among the first investigations of rodents as bone accumulators was by researchers seeking to untangle the origins of South African archaeofaunas containing australopithecines. In his critique of Dart's ideas about hominin agency in these bone deposits, Hughes (1961) was among the first to note the bone-collecting habits of Cape porcupines which transport animal bones to their lairs. Brain (1981) reported an extensive collection of bones (and part of a bicycle) from one South African Cape porcupine den.

North American wood rats (*Neotoma* species), also known as pack rats, transport diverse objects, including bones, to their nests in caves, burrows, or abandoned human structures (Hoffman and Hays 1988). These accumulations are unlikely to be mistaken for human products when encountered in isolation, where they are useful in paleoenvironmental reconstructions (e.g. Lomolino et al. 1989). However, given wood rats' penchant for sheltered locales, they sometimes set up housekeeping in a cave, rock shelter, house, or pueblo previously used by humans. This presents zooarchaeologists with the problem of separating bones likely to have been introduced into the locale by wood rats from those attributable to human agency. Hockett (1989) sought criteria to help with this problem, analyzing modern wood rat nest contents from Gunnison County, Colorado. He found that simple measures of modification intensity were not helpful: 51% of all *Neotoma*-collected bones from nests displayed carnivore modification, and relatively few showed rodent gnawing marks.

13.3.1 Rodent Gnawing Marks

Rodent species appear to prefer gnawing dry compact bone over fresh, but Rabinovitch and Horwitz (1994) observed Asiatic porcupines (*Hystrix indica*) gnawing greasy bones, as have captive Cape porcupines. I have collected heavily rodent-gnawed specimens in California that retain a good deal of bone grease (Fig. 13.15), though no soft tissue. Rodents can gnaw an element lightly, leaving a few tooth marks on it, or they can gnaw so much that an element's osteological and taxonomical identifying features are removed. Brain (1981) and Shipman and Rose (1983) provide excellent illustrations at macroscopic and SEM magnifications of rodent modifications to bone. Morphological features can be summarized as follows:

1. Rodent tooth marks are relatively wide, being two more or less parallel troughs. The marks are slightly concave, reflecting the somewhat convex leading edges of rodent incisors (Figs. 13.13 and 13.14).

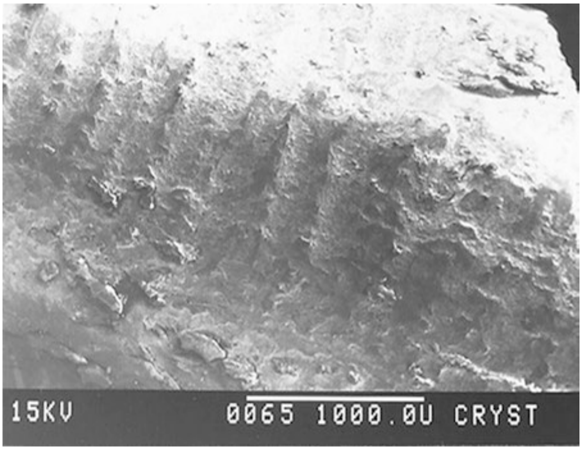

Fig. 13.13 SEM micrograph of a rodent-gnawed bone, showing ridges and troughs created by opposing first incisors scraping the bone surface. Note breadth, concavity, and regularity of spacing in relation to carnivore tooth scores (e.g. Fig. 12.1) (Unpublished SEM micrograph by Sandra Olsen, used with her permission)

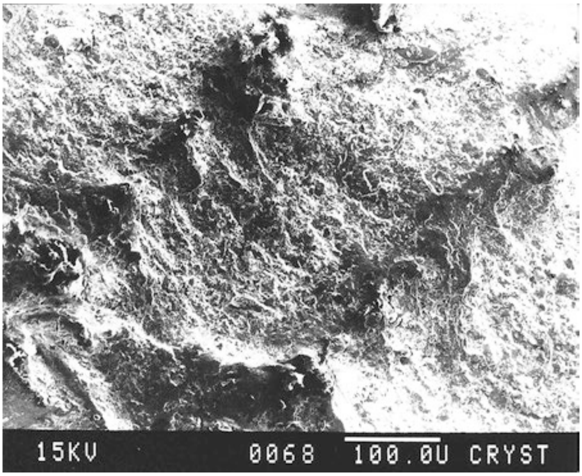

Fig. 13.14 SEM micrograph at higher magnification, showing details of the ridges and troughs created by opposing first incisors scraping the bone surface, as well as chatter marks transverse to the line of the trough caused by teeth “stuttering” over the bone surface. Scale bar 1000 microns. (Unpublished SEM micrograph by Sandra Olsen, used with her permission)

Fig. 13.15 A mule deer (*Odocoileus hemionus*) radioulna gnawed by rodents. Note the parallel-sided troughs formed in the bone by opposing rodent teeth and “sculpting” of the gnawed edge of the bone (Photo by Don Harris of specimen collected by the author)

2. Viewed closely, rodent tooth marks often display chatter marks, or ridges perpendicular to the main troughs, where the teeth skipped harmonically across the bone (Fig. 13.14).
3. Rodent tooth marks on one surface of an element or fragment have matching tooth marks on another side, made by the opposing set of incisors during gnawing (Fig. 13.16).
4. Rodent tooth marks may overlap one another due to repeated gnawing, sometimes making them difficult to distinguish in cross-section. They differ from V-shaped cut marks in their cross-section and lack of striations.

Maguire et al. (1980) have reported some furrowing by rodents in cancellous tissues in epiphyseal ends of long bones, as did Rabinovitch and Horwitz (1994), nearly always associated with distinctive rodent gnaw marks on compact diaphyseal bone. The inference is that rodents probably are the modifier creating the furrows. Burrowing rodents may gnaw bones after they are covered by sediments, although

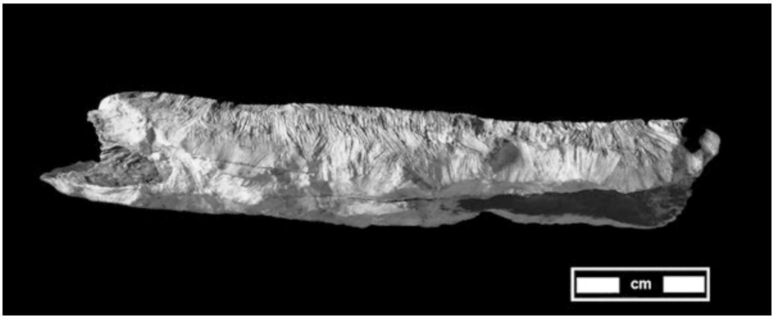

Fig. 13.16 A bovine (*Bos taurus*) metatarsal, showing very heavy gnawing by rodents, with the bone's overall shape altered by the gnawing (Photo by Don Harris of specimen collected by the author.)

they do not appear to gnaw diagenetically altered bones. Rates of gnawing in wild *Hystrix indica* porcupine accumulations evaluated by Rabinovitch and Horwitz were relatively low, under 10% of the entire accumulated assemblage. As foreshadowed in this discussion, the next chapter turns to human tool-mediated modifications to bone.

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