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NUMBER 2

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BREATHING LIFE INTO FOSSILS:

Taphonomic Studies in Honor of C.K. (Bob) Brain

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Front cover, clockwise from top left.

Top left:
Artist's reconstruction of the depositional context of Swartkrans Cave, South Africa, with a leopard consuming a hominid carcass in a tree outside the cave: bones would subsequently wash into the cave and be incorporated in the breccia deposits. © 1985 Jay H. Matternes.

Top right: The Swartkrans cave deposits in South Africa, where excavations have yielded many hominids and other animal fossils. ©1985 David L. Brill.

Bottom right: Reconstruction of a hominid being carried by a leopard. © 1985 Jay H. Matternes.

Bottom left: Photograph of a leopard mandible and the skull cap of a hominid from Swartkrans, with the leopard's canines juxtaposed with puncture marks likely produced by a leopard carrying its hominid prey. © 1985 David L. Brill.

Center: Photo of Bob Brain holding a cast of a spotted hyena skull signed by all of the taphonomy conference participants. © 2004 Kathy Schick, Stone Age Institute.

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CHAPTER 16

CARNIVORA AND CARNIVORY: ASSESSING HOMINID TOOTHMARKS IN ZOOARCHAEOLOGY

TIM D. WHITE AND NICHOLAS TOTH

ABSTRACT

The zooarchaeological implications of hominid bone chewing are relatively uninvestigated despite much progress in actualistic and archaeological research since C.K. Brain's classic 1960s studies of Hottentot/canid bone modification. Many investigations continue to make the unwarranted assumption that all evidence of chewing in zooarchaeological assemblages is attributable to nonhominid carnivores (the term "gnawing" is restricted here to rodents). In this contribution we evaluate some biases that may be responsible for the observation that hominid chewing continues to be underestimated or ignored in zooarchaeological contexts. We review the ethnoarchaeological and experimental evidence for hominoid chewing traces on bones. To illustrate issues surrounding the role of hominid teeth in patterning zooarchaeological assemblages we consider two cases of inferred cannibalism in the archaeological record. Fertile ground for continuing studies is identified, but given the morphological and anatomical parallels between the masticatory systems of hominids and carnivores, it appears that linking chewing damage with specific agents in archaeological contexts will be more difficult than previously imagined.

INTRODUCTION

> If the student should ask me how the paleontologist tells the difference between hyaena and human teeth-marks on a bone, and particularly a bone that has been rotting in a cave since the everlasting hills were builded, I should answer that I don't know.
>
> Mark Twain 1871 (in Neider, 1961)

> Good science consists of strategically using prior knowledge to make projections from better-known domains to less well-known domains.
>
> Binford (2001)

By virtually any definition, Bob Brain has conducted exceptional science for nearly his entire life. His career as a paleobiologist is exemplary. There is hardly a topic in current human evolutionary studies untouched by his work.

During the two decades that followed Brain's 1981 classic *The Hunters or the Hunted? An Introduction to African Cave Taphonomy*, archaeological and actualistic studies of bone modification intensified and diversified. As a consequence, a routine component of any modern analysis of bones from archaeological contexts is the observation and recording of pits, scores, and fractures created by mammalian teeth. Such modifications are usually classified as "carnivore" damage. Standardization of the terms used to describe the modifications has proven elusive. Furthermore, a lack of inter-analyst consistency and replicability frequently plagues such descriptive and comparative studies.

Even the seemingly simple classificatory label "carnivore damage" is fraught with ambiguity. This is because the term "carnivore" has two meanings. One designates a mammalian order. The other is a term used to denote diet. The family Hominidae is precariously positioned relative to this ambiguity. Once the hominid niche was broadened by lithic technology during the Pliocene, consumption of large terrestrial mammals was no longer the exclusive realm of the Carnivora (see Stiner, 2002 for a review of what happened subsequently). This dietary shift is most recognizable by the stone artifacts with which it appears to have been associated—and by the signatures and patterns that the edges and surfaces of these implements leave on bones and bone assemblages. Ethnographic and primatological analogy both suggest that muscle and marrow-eating hominids would have chewed bones of the medium and large mammals they butchered.

Inspired by Bob Brain's work in South Africa, zooarchaeologists have made great progress in actualistic and archaeological studies that demonstrate the impact of both hominid and nonhominid carnivore behavior on bone assemblages. Attributes allowing the analyst to distinguish rodent gnawing, nonhominid carnivore, and even ungulate chewing damage on bones have been identified, described, and illustrated in both archaeological and actualistic contexts (see White, 1992 for a review). Analyses of these bone modifications play a central role in ongoing discussions about early hominid behavior and ecology.

Mammalian chewing alters individual bones and affects assemblages of bones. It modifies bone surfaces and deletes bone elements and element portions. Brain's classic work comprised both experiment and observation of these effects. He studied bone assemblages generated by traditional residents of the Kuiseb River's north bank. From the beginning, Brain recognized that these ethnoarchaeological bone assemblages bore the signature of two goat-eating agents—Hottentots and their dogs. Both agents were equipped with the masticatory means to modify bone surfaces and assemblages. Brain conducted experiments to *differentiate* the various signatures of bone modification and element representation patterns produced by these different taphonomic actors on the Hottentot ethnoarchaeological stage. He wrote:

> "It seemed advisable to separate the damage done to goat bones by the Hottentots themselves from that caused by their dogs…It was surprising to find that the Hottentots were capable of inflicting considerable damage on bones with their teeth…It is to be expected that Stone Age people would have done even greater damage to bones with their teeth than do Kuiseb River Hottentots" (Brain, 1981: 17-18).

Few of the hundreds of subsequent taphonomic and zooarchaeological studies inspired by Brain's work on South African cave assemblages have pursued research into bone modification caused by human chewing. As a consequence, our understanding of this phenomenon remains woefully inadequate. This is particularly surprising since many of these investigations are aimed at understanding the relationships between hominids and bone assemblages with which they are associated by their presence or archaeological droppings. The ability to discriminate bone chewing by hominids would be of central importance in archaeological studies ranging from the behavior of the earliest hominids to investigations of ethnohistorical cannibalism. Studies spanning wide cultural, spatial and temporal scales would benefit from the ability to discern and diagnose traces of chewing left by hominids as opposed to nonhominid carnivores. This has been clearly recognized for over a quarter of a century (see Binford's observations in 1981, described below), but the research remains unconducted.

In the sections that follow, we explore issues involving the subject of hominid bone chewing. Several examples illustrate how analysts have ignored the role that early hominid chewing might have played in generating modifications and patterns of representation in zooarchaeological assemblages. This lack of consideration is attributable to several factors, identified here as a series of biases that appear to have been imposed by modern human culture and anatomy. Anatomically, many researchers have seriously underestimated the potential of the early hominid masticatory complex to inflict osteological damage during chewing. Culturally, focus on hominids as technological creatures and modern western table manners may be co-conspirators in this analytical lapse. We discuss attempts to diagnose different bone chewers and address the likelihood that a substantial degree of equifinality will ultimately be demonstrated when the requisite studies have been conducted. Our report concludes with two presentations of case studies involving the possibility of human chewing of bone in contexts suggestive of cannibalism.

IGNORING HOMINID CHEWING

The presence and activities of hominids are routinely inferred by paleoanthropologists on the basis of surface modifications to bones in zooarchaeological assemblages. Such inferences are today universally accepted. They are regularly grounded in solid actualistic research on cutmarks, hackmarks, percussion striae, and the like.

Quantification of bone surface modifications as well as skeletal element and element portion representations within assemblages is now standard practice in zooarchaeological research and reporting. However, debate persists on the standards to adopt in observation and recording of chewing modifications and extends to interpretation of the behavioral significance of modification to body part representation. For example, in a Lower Paleolithic context, the question of whether early hominids hunted, aggressively scavenged, or passively scavenged remains unresolved (Lupo and O'Connell, 2002; Domínguez-Rodrigo, 2003; O'Connell and Lupo, 2003; and references therein). The debate prominently features assessments of chewing damage to hominid-modified bone assemblages.

The residues left by primate and carnivore agents on African Plio-Pleistocene taphonomic landscapes have both spatial and physical components. For some occurrences, lithic assemblages have been subjected to repeated analysis and faunal remains have had their surfaces and proportions intensively and exhaustively investigated. The resultant data sets, derived from small windows excavated into vast paleolandscapes, comprise the scant evidence on which paleoanthropologists base key inferences regarding early hominid behaviors. Given the paucity of data, it is neither surprising that debates concerning these inferences continue, nor difficult to predict that studies of bone modification will continue to play a central role in such research far into the future.

Bone modification studies have a long and distinguished history in archaeology. Chewing-induced marks captured interest early, attested by Buckland's work in the early 1800s. By 1938 Pei was cautioning that errors of interpretation might befall investigators who neglected the role of mammalian carnivores in accumulating and modifying assemblages.

The FLK 22 "Zinj" excavation and its derivative contextual, artifactual, and zooarchaeological data sets have played central roles in discussions about the activities of Plio-Pleistocene hominids at Olduvai Gorge. As noted by numerous analysts of such assemblages, "actors" or "agents" active in the FLK taphonomic setting included wind, water, and ultraviolet light. Also present were nonhominid tramplers, nonhominid chewers and gnawers, plants with acidic bone-etching roots, and rock-wielding hominids (summarized by Capaldo, 1997).

The zoological agents of greatest behavioral importance in Plio-Pleistocene taphonomic settings such as FLK "Zinj" are nonhominid carnivores of various taxa. These animals shared the arena with at least two sympatric hominid species. Bone modification studies show unequivocally that at least one of these hominid species played active roles in influencing the recovered bone assemblages. The exact nature of such roles remains unclear. Furthermore, it is currently nearly impossible to infer the identity of the one or multiple contemporary hominid species involved with the lithic technology accompanying the bone assemblages.

Attribution of bone surface modifications documented on the Olduvai assemblages is most often accomplished by dichotomizing the bony trace evidence according to the agents inferred to have created it. The presence of "carnivores" is often inferred by chew marks. In contrast, the presence of hominids is inferred by signatures of tissue removal (cutmarks) and marrow acquisition (hammer and anvil striae; inner conchoidal scars on limb bone midshafts).

In Paleolithic archaeology, there is often the implicit assumption that any tooth marks discernable on a bone were made by Carnivora (hyaenids, felids, canids; but see contra, Brain, 1981; White, 1992; Pickering and Wallis, 1997). It is a short but dangerous step to then infer the order of access by the hominids and other carnivores in these Plio-Pleistocene settings. The superimposition (overprinting) of chewing traces and cutmarks/percussion damage are frequently the basis of such inferences, usually with the unwarranted assumption that the toothmarker belonged to the Carnivora. How valid is this assumption when we know that some early hominids even scarred their own *incisors* with sharp stone tools they used to slash tissue held between their front teeth (Fox and Frayer, 1998; Lozano-Ruiz, et al., 2004)? Did they not chew, too?

Paleoanthropologists can safely assume that nonhominid carnivores did not wield stone tools, and hence were not responsible for cutmarks or percussion processing evidenced by the faunal remains from such sites. But how safely can they assume that every toothmark on a bone was created by a nonhominid carnivore? And how might the relative abundance values of skeletal elements in an assemblage be apportioned to nonhominid carnivore chewing and transport as opposed to hominid defleshing, percussive marrow extraction, and chewing?

Negligible attention has been afforded to the possibility that hominids themselves could, and probably *did* chew bone portions. These were primates obviously attracted to meat and marrow. It is unrealistic to ignore the possibility that trabecular bone of the ungulate carcasses, often covered by only a thin bony cortex, was exploited by early hominids.

The mastication of bones by hominids would not have been limited to scarring of bone surfaces. It is predicted from Brain's Hottentot assemblages that these actions would also have deleted bones and bone portions from prehistoric sites. If both nonhominid carnivores and hominids themselves played roles in patterning the modifications and deletions that resulted in the recovered bone assemblages, how might their relative contributions be determined?

Actualistic studies of surface traces and fragmentation patterns have made it possible to set forth criteria that allow investigators to diagnose marrow processing via hammerstone versus marrow processing by nonhominid carnivore chewing (e.g., Blumenschine, Marean and Capaldo, 1996). Methodological problems persist (Lupo and O'Connell, 2002). Even in the apparently routine area of toothmark identification, wide inter-analyst disparities have arisen. As Capaldo (1997) notes, such disparities can be significant. Toothmark recognition for the Olduvai "Zinj" assemblage illustrates such methodological difficulty. Blumenschine (1995) reports tooth mark percentages four times higher than those reported by Bunn and Kroll (1986) for the same assemblage. This is clearly a serious problem but even *less* progress has been made in distinguishing potential hominid and nonhominid chewing on the *same* assemblages.

The magnitude and significance of this problem is manifested in Capaldo's (1997) dichotomization of "hominids" versus "carnivores" in the "Zinj" bone assemblage (see Capaldo, 1997 Table 1). To hominids he attributes "tool marks, hammerstone notches, spiral fractures, and bone fragmentation" (p. 559). To "carnivores" he attributes "tooth marks, tooth notches, spiral fractures, digestive etching, deletion of low density skeletal parts and portions, and bone fragmentation." But couldn't hominids have also created tooth marks? And couldn't they, by simple chewing, have effectively deleted low density skeletal parts and portions, *even without artifacts*?

In his book on the Olduvai evidence, Potts (1988: 145) states that "…one of the strongest effects of carnivore modification, which occurs at each Olduvai site, is the destruction of long bone ends." According to Potts' critique of colleagues (Bunn and Kroll, 1986) who interpreted the same Olduvai assemblages differently:

> "…the carnivore contribution to site formation is largely ignored and overshadowed by their attention to tool cut marks. As noted repeatedly here, carnivore damage to the bones indicates not only the presence of large and small scavenger/predators at the sites but also suggests that hominids were not responsible for consuming some portion of the edible tissues represented at these sites…the action of carnivores, as one element of site formation, is an important, consistent part of the context of hominid activities at Olduvai and, in fact, informs about the nature of hominid activities at these sites" (Potts, 1988: 306-307).

Perhaps, but it is obvious that *if* the "carnivore" responsible for a significant part of this "damage" and deletion were one of Olduvai's hominids, *then* the nature of the hominid/nonhominid carnivore activity would require a different interpretation. The dichotomization of the damage types according to the formulae: toothmarks = nonhominid carnivore, and cutmarks = hominid, while semantically and conceptually attractive, is illusory and naïve. It appears possible that advocates on either side of the debate about early hominid carnivory may have missed a significant component of behavior by employing such false dichotomization.

Arguments over the behavioral significance of the Olduvai zooarchaeological assemblages continue nearly unabated. The most recent incarnation is a debate between Lupo and O'Connell (2002, and O'Connell and Lupo, 2003) and Domínguez-Rodrigo (2003). At issue is the degree to which cutmark and toothmark frequencies may be indicative of early hominid carcass procurement and processing. Neither party explicitly considers the potential influence of hominid-generated toothmarks on their arguments. Indeed, this accurately reflects a very large literature on these assemblages—mere lip service has usually been paid to possible hominid participation in the creation of the toothmarks—bone modifications otherwise meticulously quantified, but almost universally attributed to "carnivores."

Oliver (1994: 270), at least, explicitly brings up the potential confounding effect of such participation: "Given the demonstrable hominid involvement with the fossil assemblage [references] it is likely that hominid teeth created at least some tooth marks." He goes on to explain his scoring of the Olduvai assemblages as follows:

> "Until actualistic data become available documenting differences between primate and carnivore-inflicted damage, I assume observed tooth pits and scores identify carnivores, but recognize that early *Homo* created at least some tooth marks."

The question of how many—and which ones—is patently important.

IDENTIFYING BIAS

The widespread inattention to the possibility that early hominids chewed bones and thereby produced bone modifications and deleted spongy bone parts in a manner that mimics patterns of damage usually attributed to Carnivora stems from at least three major causes. First is the modern practitioner's unfamiliarity with the masticatory apparatus and gnathic capabilities of hominids, particularly now-fossilized hominids. Second, some inattention seems predicated on the fact that despite Brain's call for ethnoarchaeological and experimental research in this area, there has been very little progress. We consider these aspects in subsequent sections. A third, less apparent, but perhaps even more important factor explaining why hominid chewing is relatively ignored involves *bias***.**

A well-known bias in paleontology is what Raup (1979) has termed the "pull of the recent," the phenomenon by which species diversity appears greater in more recent deposits because of more complete sampling of younger units and misassignment of sampled fossils to recent taxa. A similarly well-known and parallel bias in archaeological research within Holocene and historic contexts is what Wobst has called the "tyranny of the ethnographic record." This is the phenomenon by which the richness of the ethnohistorical record in any geographic locale can skew interpretations of archaeologists working in the same area.

Parallel pitfalls pervade paleoanthropology. Recovery operations involving the Olduvai Hominid 62 specimen at the bottom of Olduvai Gorge in Tanzania, provided the excavators an opportunity to listen in on Serengeti tourists whose vehicles stopped on the adjacent road. A common theme of these overheard amateur conversations was incredulous wonderment: "why would anybody want to live in this dry gulley?" In assessing past environments, a fundamental challenge facing the student of paleoanthropology is to subdue perception of modern landscapes as a first step toward understanding the ancient precursors of these landscapes, thus escaping what might be called the "tyranny of modern topography."

Bias in the geographic realm is paralleled by another "pull of the recent" in the biological realm. Because paleoanthropologists are anatomically modern humans, ever since Darwin theirs has been a science beset by a "tyranny of evolutionary endpoints." In hominid paleontology, a classic example is the widespread but demonstrably false notion that the last common ancestor of African apes and humans was a chimpanzee. We know for certain that in anatomy and behavior early hominids were neither diminutive humans (although some have been given cute human names), nor upright chimpanzees (even though they are frequently depicted as such). If accurate interpretation of human origins and evolution is the goal, then using *either* extant organism as a proxy for morphologically and behaviorally extinct ones is fraught with epistemological peril. Early hominids were not humans, nor were they busy becoming humans. Exactly what they were, and what they were doing, is the research problem. Pretending to solve it with inappropriate analogies will not suffice.

In paleoanthropological assessments of bone assemblages associated with hominids of the Plio-Pleistocene, there may well be two other "tyrannies" at play. The first is the "tyranny of modern human mastication." The second is the "tyranny of table manners." Brain's actualistic and experimental studies nearly forty years ago allowed him to escape the confinement of these twin tyrannies. These studies allowed him to write that "Stone Age people" could have done even more damage to bones than what he had witnessed the Hottentots doing with their teeth.

White (1992: 155) noted the paucity of post-1981 work on human chewing of mammalian bone as follows: "This is an extremely underdeveloped, but important area of potential actualistic research." As Brain appreciated, the fact remains that hominid chewing of bone at archaeological sites has the potential to severely condition the assemblages available for interpretation across a wide sweep of archaeological circumstances.

Disproportions created by nonhominid carnivore chewing are well known and thoroughly documented from forensic (Haglund et al, 1988), ethnoarchaeological (Binford, 1978, 1981), and experimental work (Lupo and O'Connell, 2002) on chewing by nonhominid carnivores. Some important generalities have emerged from these studies regarding surface modifications and element preservation. For example, as summarized by Grayson (1988), canids prefer to attack the ends of major limb bones, whereas hominids tend to concentrate on midshaft portions by percussion. This generalization holds fairly well across a range of carnivore body sizes and bone destruction capabilities.

Both hominids and species of Carnivora can *delete* bones and bone portions through chewing. The *presence* and *activity* of hominids versus nonhominid carnivores may be demonstrated on the basis of accompanying bone modifications seen on assemblages. Cutmarks and percussion-related striae are only left by hominids. However, just because hominids had developed the percussive technology to access marrow and nutritive spongy bone, there is no reason to imagine that they simultaneously abandoned the tools of mastication that had served them and their ancestors so well over the previous hundreds of millions of years. Thus, Selvaggio's (2001: 469) inference that "it is unlikely that hominids frequently inflicted tooth marks on bones," and her contention that "[t]he development of stone tools is generally acknowledged to be a cultural innovation necessitated by the lack of shearing dentition in the hominid line" both appear to be entirely unwarranted.

Hominids seeking nutrition in the spongy ends of long bones can access it by chewing or pounding these portions between hammer and anvil. Oliver's (1994: 287) analysis of the FLK "Zinj" assemblage recognizes the possibility of both:

> "…the severity of the damages [sic] is more than required to remove marrow; the severity of hammerstone-induced damage demonstrates concern with, and consumption of the blood-rich cancellous ends. This intense processing may explain part of the loss of epiphyseal ends noted previously by Bunn."

Such processing, either for direct consumption or for grease rendering, can mimic carnivore activity in terms of the residual element and element portions. Whether the agent of destruction walked on two or four legs, the archaeological fallout of bone element and portion *survival* is conditioned by the structure of the bones themselves. When bone modification patterns and *traces* are taken into account, this ambiguity is reduced (see White, 1992). But what about hominid chewing of bone? Ethnographic and primatological observations suggest that hominids could have extracted nutrition in this manner. Such potential exploitation will not be recognized by preemptively denying its existence, by simple quantification of bone survival, or by assuming that hominid-induced bone modification is exclusively imposed by a stone edge. How might we recognize hominids who exploited the spongy parts of bone by chewing them? The required actualistic experimentation and observation advocated by Brain has yet to be conducted.

RECOGNIZING CARNIVORE SPECIES

Substantial effort has gone into attempts to identify chewing modifications imposed by different *species* of Carnivora. Virtually none has been invested on attempting to differentiate these modifications from those left by hominid chewing. Haynes (1980) represents an early attempt to sort among carnivores based on damage patterns observed on spongy bone. He followed this (Haynes, 1983) with quantitative work comparing tooth puncture diameters with canine tooth profiles. Unsuprisingly, given the conical nature of many teeth, differentials in tissue penetrability, and inter-animal variation in bite force, Haynes found substantial ambiguity. Other investigators have attempted to identify carnivore species in more ancient contexts based on their tooth impressions. Oliver (1994: 285), faced with "carnivore damage" on 54% of the MNE from the FLK "Zinj" assemblage, argued:

> "…carnivore damage data also suggest the type or size of carnivore involved…rather a smaller carnivore that could make use of small meat scraps adhering to small bone fragments…these carnivore damage frequencies also corroborate the inference that carnivores were an important taphonomic agent at FLK Zinj."

Potts (1988), based on the same assemblages, implicates larger carnivores (hyaenids) in their generation.

Subsequent work in actualistic and archaeological contexts has explored bone modifications with the intent of identifying the nonhominid carnivore species involved in their creation. In her work with faunas from Late Pleistocene Italian caves, Stiner (1994) investigated the relationship between diameter of puncture marks and carnivore body size. She found that "The data separate carnivore agencies into two general body size groups, large and small, and do not distinguish hyaena from wolf, or wild cat from fox" (Stiner, 1994: 133). In her discussion, no consideration is given to the possibility that the smaller punctures were made by the deciduous teeth of larger species.

Selvaggio and Wilder (1995: 466) examined tooth marks "…selected by their resemblance to undamaged tooth cusps or complete crowns. Such marks are generally described as tooth pits." They cite Binford (1981) as the source for their adopted nomenclature, but his definition pertains to "pitting" rather than to individual pits. Given this and other ambiguities regarding how the marks that she measured were actually selected and defined, the results of Selvaggio and Wilder's study are difficult to interpret. They did conclude (not surprisingly), that pits on cancellous bone were larger than those on compact bone, and that it was difficult to distinguish between the known carnivore taxa used in her experiments.

Domínguez-Rodrigo and Piqueras (2003) performed another actualistic study that combined data from assemblages with elements chewed by captive and wild lions, jackals, bears, hyaenas, dogs, and baboons. They conclude that "conspicuous" (undefined) tooth marks can be used to distinguish three groups of carnivores, small, medium, and large. Like Stiner and Selvaggio and Wilder before them, these authors do not explicitly consider juvenile carnivores or the impact of their milk dentitions. In agreement with the latter authors, Domínguez-Rodrigo and Piqueras (2003: 1386) "are skeptical that specific carnivore taxa can be identified from tooth mark analysis alone."

Pickering et al. (2004) attempt to use these findings by concentrating, like Selvaggio, on "tooth pit" dimensions to evaluate the role of leopards in Swartkrans assemblage creation. A major advance of their work is its attempt to define what they mean by "tooth pit":

> "Tooth pits are bone surface modifications imparted by animal chewing and appear as discrete, roughly circular marks in plan view and result from scarring of bone without [significant] inward crushing of the bone cortex" (Pickering et al., 2004: 596).

IDENTIFYING TOOTHMARKS

In her extensive assessment of Pleistocene Italian cave faunas, Stiner (1994: 106) reported that "[n]o evidence of gnawing by human teeth was found," but did not suggest how such damage might have been recognized in the first place. As outlined previously, bone chewing by hominids might impact a bone assemblage in two ways, deletion or surface modification.

Despite decades of research, a diverse and often redundant vocabulary is currently employed by analysts to describe tooth scratches, punctures and pits made on bone surfaces by chewing mammals (Binford, 1981; Shipman, 1981; Cook, 1986; Lyman, 1987; Marshall, 1989; White, 1992; Blumschine et al., 1996). Investigations have failed to distinguish among extant species of Carnivora on the basis of these modifications except in the most general terms. Most of these studies have ignored the possible contribution of hominid chewing to this already difficult-to-disarticulate problem. In 1992 (p. 155) White noted:

> "It is evident from simple mechanical considerations that substantial overlap between human and carnivore chewing damage on bones will be shown by future research in this area…Meanwhile, tooth striae, punctures, and tooth pits should not be attributed to taxon in archaeological bone assemblages until further actualistic work is completed."

During the decade that has passed since that caution, substantial work has been done in attempts to discriminate between *nonhominid* carnivore *species* based on surface modifications to bones (see previous section). However, little further research has been conducted on hominid chewing and its effects.

Brain's actualistic studies of Hottentot modification of bones during the 1960s included an experiment in which he provided a small subadult goat to the local people. After the goat tissues had been consumed in the traditional manner, the remaining bones were collected prior to feeding to the village dogs. Brain (1981) provided a summary of damage to the skeleton. Maguire, Pemberton and Collett (1980: 88) echoed Brain's observations about the extent of bone damage by human chewing, and elaborated as follows:

> "It was surprising to note that the Hottentots were capable of inflicting a considerable amount of damage on the goat bones with their teeth. Ragged-edged chewing, practically indistinguishable from that produced by hyaenas on the more frail skeletal elements, was observed in particular on the scapulae and pelvic bones…Splintering was also common to both the carnivore and hominid samples."

These authors note that the five categories of damage encountered on their comparative hyaena-modified actualistic sample (striations, pitting, grooves, scooping of cancellous bone, and etching by stomach acids) were *not* observed on the Hottentot sample. They went on to report that crushing by human teeth represents a category of damage that:

> "…can be reproduced by repeated crunching with the molars and premolars on a fairly soft bone, such as a chicken limb or immature goat or sheep bone, after the articular epiphyses have been removed so as to leave a splintery, inwardly depressed margin to the shaft." (p. 88)

No further work with the Brain Hottentot sample has been conducted, but Pickering and Egeland (personal communication, 2004) are currently re-analyzing it.

Additional studies of chewing of mammal bone by modern people have been ethnoarchaeological and archaeological in nature rather than experimental. For example, in her 1989 work on northern Kenyan pastoralists, Gifford-Gonzalez decries the lack of needed experimental and observational research on the production of bone assemblages. In particular, she notes that much of the chewing damage she observed on faunal remains in a Dassanetch bone assemblage could not be attributed specifically to either human or nonhominid chewing (she cites Solomon's unpublished 1985 bachelor's thesis as noting the possibility that human teeth might mimic carnivore marks). The ethnoarchaeological literature contains many accounts of modern people chewing off the ends of long bones (e.g., Jones, 1983). Even extant hunter-gatherers continue to provide ethnoarchaeological evidence of hominid chewing and consumption of spongy bone:

"On some long bones, cancellous tissue in articular ends may be gouged out with a knife or some other pointed object and eaten. Ribs are sometimes snapped or chopped into sections, and the broken ends gnawed and sucked" (Lupo and O'Connell, 2002: 87).

The necessity for additional experimental work on hominid chewing of bone is neatly illustrated by Binford, whose 1981 book echoed Brain's concern regarding experimentation:

> "This is an area where diagnostic properties might well be developed through direct experimentation with modern subjects. However, the gnawing would have to be directed and controlled for the strength of the subjects and they could not be allowed to select what they wanted to gnaw. Instead, the experimenter would have to instruct his subjects to gnaw assigned anatomical parts in specified ways so as to obtain as complete a picture as possible and likely under different conditions…we need data on this problem before tooth modifications on bones can be assigned to nonhuman agents in a totally reliable manner" (Binford, 1981: 148).

Three years later, Binford illustrated and described damage to a Middle Stone Age Klasies bushbuck metatarsal. He attributed it to hominid chewing (Binford, 1984).

Given the constraints of human subjects committees at institutions of higher learning, to say nothing of the expense of cosmetic and restorative dentistry, the lack of post-Brain bone chewing experimentation in humans is at least partly understandable. However, surprisingly little ethnoarchaeological research has been conducted on this topic. Meanwhile, bone chewing by captive and wild chimpanzees has proceeded in productive directions.

Three different studies have noted that modern chimpanzees can and do modify the bones of prey carcasses they consume, and that various aspects of that modification can mimic modifications documented for Carnivora. Plummer and Stanford (2000) report on analysis of a small bone assemblage made by chimpanzees at Gombe, and Tappen and Wrangham (2000) report on another taphonomic study of bones from chimpanzee dung at Kibale. Inspired by Brain, Pickering and Wallis (1997) undertook a captive study, finding that chimpanzees were capable of producing mastication damage similar to that produced by nonprimate carnivores.

RECOGNIZING HOMINID TOOTHMARKS

Hominid teeth, both fossil and modern, are often mistakenly presumed to be so excessively low-crowned as to be incapable of inflicting the kind of damage that is routinely attributed to Carnivora in zooarchaeological assemblages. Maguire, Pemberton and Collett (1980: 88-89) consider the masticatory apparatus of early hominids as follows:

> "Although the teeth of **[***Australopithecus***]** *africanus* were larger and more robust than those of living Hottentots and were thus potentially capable of inflicting a greater degree of damage, it is unlikely that the bunodont teeth of this species were capable of producing pitting, striations, grooves or scooping damage. There is certainly no basis for attributing such damage to the teeth of hominids when it can be demonstrated conclusively that carnivores can and do produce such damage."

Pickering and Wallis (1997: 1116) follow at least some of the same questionable logic:

> "While modern chimpanzees are not necessarily the best models for study of all aspects of Pliocene hominid behaviour, we feel that they serve as good models for deriving predictions of early hominid mastication damage on archaeological bones, due to the close similarities in chimpanzee and Pliocene hominid morphology, technological grade and bite force. While the chimpanzee dental arcade is different from that of the gracile australopithecines in shape and in having more procumbent incisors, larger canines, sectorial lower third premolars and smaller cheekteeth (see Swindler, 1976), we contend that the posterior dentitions of the two taxa are more similar to each other than either is to the Carnivora.

> This is especially true regarding the bunodont configuration of both hominoids' cheekteeth."

There are two kinds of effects that hominid chewing might have on bones; the crushing/deletion of spongy portions (usually near-epiphyseal), and the surface marking of more resistant portions (mostly diaphyseal) of bone elements. In an effort to better visualize the kind of damage that early hominid teeth might impose on a bone surface, we performed some simple comparisons.

Figure 1 illustrates the general crushing potential of the early hominid dentition compared to modern humans and chimpanzees. Note that the A.L. 288-1 specimen ("Lucy") of *Australopithecus afarensis* (one of the earliest and least specialized species of its genus) had diminutive body size coupled with large postcanine teeth. Note also how large the postcanine platform of its sister species, *A. africanus*, can be. The dentitions of all the Plio-Pleistocene hominids were occluded under the force of a powerful masticatory apparatus (Kimbel et al., 2004). Crushing of nutritious spongy bone under a thin cortex would have been easy for any of these creatures.

There is abundant evidence that individuals of many species of early hominid loaded their teeth forcefully against hard objects. Figure 2 illustrates the kind of damage that results from this activity. Here, massive step-fractures on the labial surfaces of the canines of a Swartkrans adult hominid show that the teeth were pressed (or impacted) against a hard object with such force that the enamel failed. Subsequent wear polish superimposed on the fracture surfaces shows that this biting happened well before the death of the individual. The illustrated teeth are from *A. robustus* of Swartkrans, but similar polished fractures indicative of forceful biting against hard objects are found throughout the hominid fossil record. It is not possible to tell whether this damage was incurred during bone chewing, or the chewing of some other hard material. Similar fractures are also occasionally observed among hyaenids and other carnivores that crush bones with their teeth. Figure 2 includes such a fractured carnivore tooth, a wild spotted hyaena—a species thought to have specific histological adaptations to mitigate against such enamel failure.

Figure 3 compares the dental "business ends" of hominid and hyaenid teeth. The term "bunodont" is adequate to describe gross morphological differences between such morphologically disparate species as hominids and horses. However, this term should *not* conceal the fact that hominid tooth cusps, particularly when little worn or deciduous, can be sharp, salient, and capable of inflicting the kinds of pits, scores, and even punctures that are often attributed exclusively to Carnivora. Modern human and modern hyaenid deciduous and permanent dentitions bear an array of cusp morphologies capable of inflicting a wide range of damage types often ascribed exclusively to different species of Carnivora.

Figure 3b shows a comparison of cusp tip morphology in the two hominid species known to have been present on the Olduvai FLK "Zinj" floor, *Homo habilis* and *Australopithecus boisei*. Both have cusps comparable in their potential to modify bone surfaces during chewing activity, and it is difficult to imagine how such surface signatures might be differentiated from those left by the wide suite of nonhominid carnivore species.

Several of the studies cited in the previous section have attempted to make taxonomic attributions from bone surface modifications through the use of dimensions of surface pits and scores. None of them measure the depths of the pits analyzed. However, it seems fair to observe that most of the surface defects measured in these studies are less than a millimeter or two deep, particularly on the cortical bone of limb bone shafts. Thus, it is not the overall morphology of the tooth, or even its cusp that is important in such comparisons. Only the cusp's tip is responsible for interfacing with the bone surface to produce the observed modification. A simple consideration of the physical parameters of bone surfaces (tissue cover, maturity, texture, density) and the factors that interface with them (sharpness, deciduous or permanent, chewing force, taxon, tooth category) reveals a complexity not easily resolved into specific alternative taxa, or even grossly different body sizes within Carnivora, let alone discriminate them from the hominids with which they shared their prehistoric taphonomic arenas.

EQUIFINALITY PREDICTED

Given the anatomical and physical illustrations provided in the last section, an unavoidable and unfortunately pessimistic prediction follows: except in very rare instances (such as a clean puncture by a taxon-specific, anatomically diagnostic tooth) no single morphological characteristic of a mammalian tooth mark on an ancient bone will allow the taxonomic identity of its maker to be unequivocally established. Such pessimism is only a slight extension of the findings of other studies already conducted and cited above.

Given such apparent equifinality (different causes producing the same end or result) involving the agents of modification responsible for scores, pits, and punctures on bones, Pickering and Wallis have followed others in advocating a configurational approach (attempting to focus on the anatomical context of the marks rather than the marks themselves). But given the variability in the species of Carnivora that have access to most archaeological bone assemblages, and these investigators' findings that bone damage caused by chimpanzee chewing is "nearly identical to carnivore gnawing damage" (Pickering and Wallis, 1997: 1125), how much room is there for optimism?

Optimism is probably only warranted at the assemblage level. Work on bone assemblages conducted with the goal of identifying the main agent of modification has taken place in a variety of archaeological contexts mentioned in previous sections. Perhaps no context has been so controversial as the one involving the question

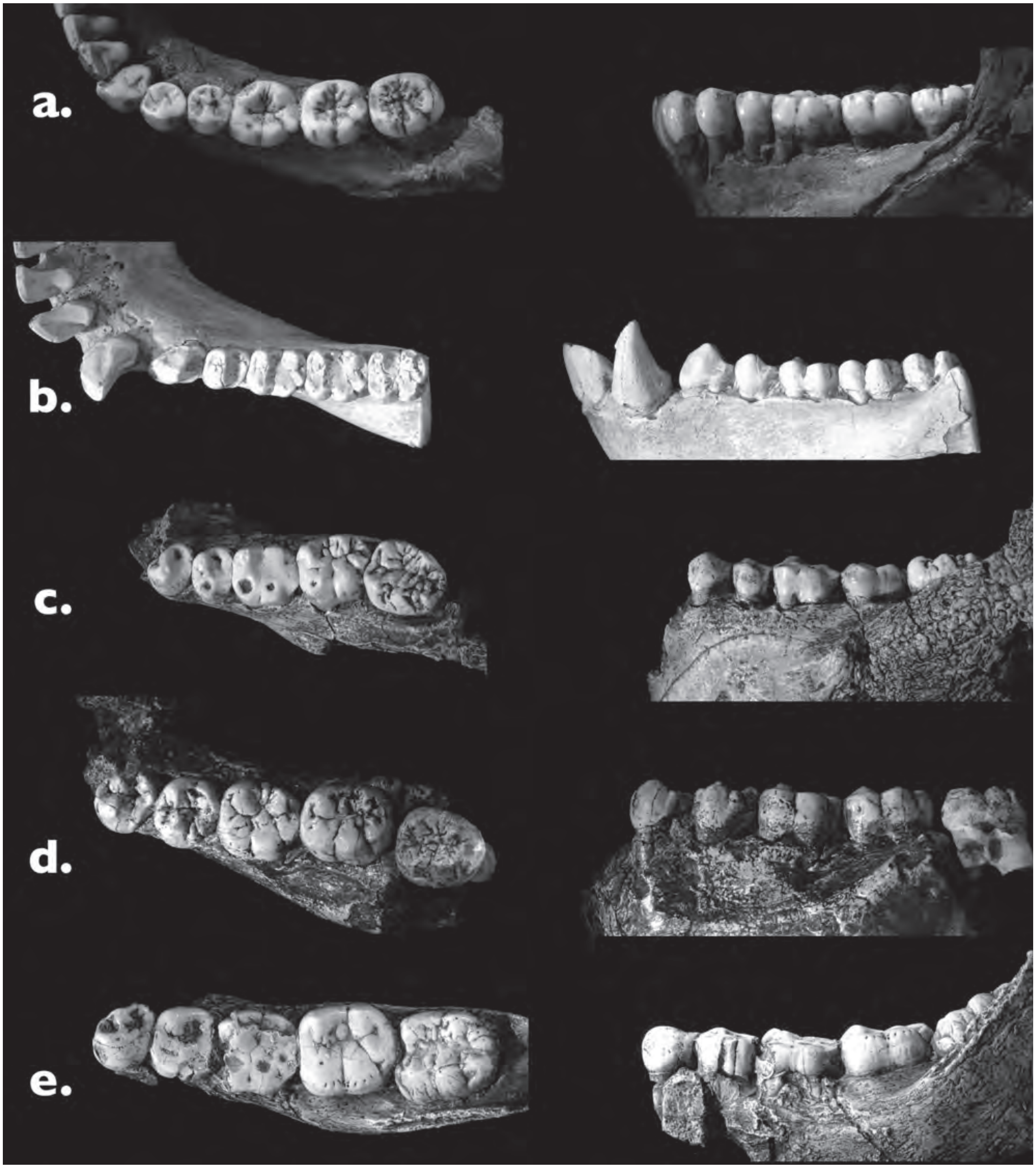

Figure 1. The masticatory apparatus of early hominids featured robust jaws and teeth fully capable of crushing many vertebrate bones, particularly spongy ends. Seen here via casts in side and occlusal views, it is evident that the dentitions of any of the fossil species had the potential to inflict bone surface modifications that would easily surpass the dramatic effects already documented for the modern human chewing. Even the primitive Australopithecus afarensis *(c; A.L. 288-1 "Lucy," reversed) was a megadont species compared to anatomically modern humans (a; Qafzeh 9) or modern chimpanzees (b; CMNH B-3412). The utterly inappropriate term "gracile" has been applied to taxa such as* Homo habilis *(d; KNM ER-1802, here with OH 16 M3, reversed) and* Australopithecus africanus *(e; STW 498), but it is clear that these megadont species also had bone chewing potentials far exceeding that seen in modern humans or chimpanzees.*

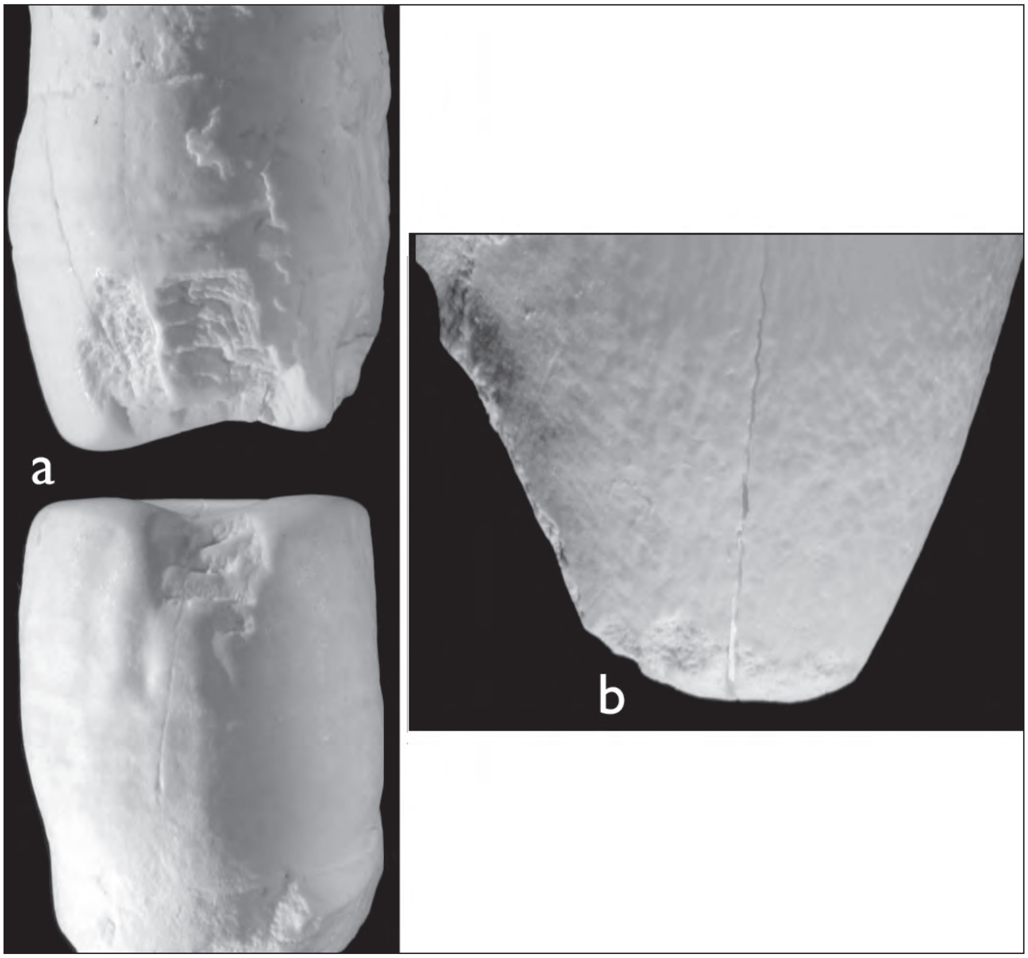

Figure 2. The probably female Swartkrans Australopithecus robustus *maxilla (SK 65+67+74) features prominent step fractures on the labial surfaces of the canines. Such damage, with post-fracture wear polish and striae superimposed to show that the trauma was incurred* in vivo*, indicates forceful biting of a hard surface. Such damage is frequently encountered in different early hominid taxa. When found in hyaenids (U.C. Berkeley MVZ specimen 173762, wild, Narok, Kenya 1981) such damage is usually interpreted as evidence of bone chewing.*

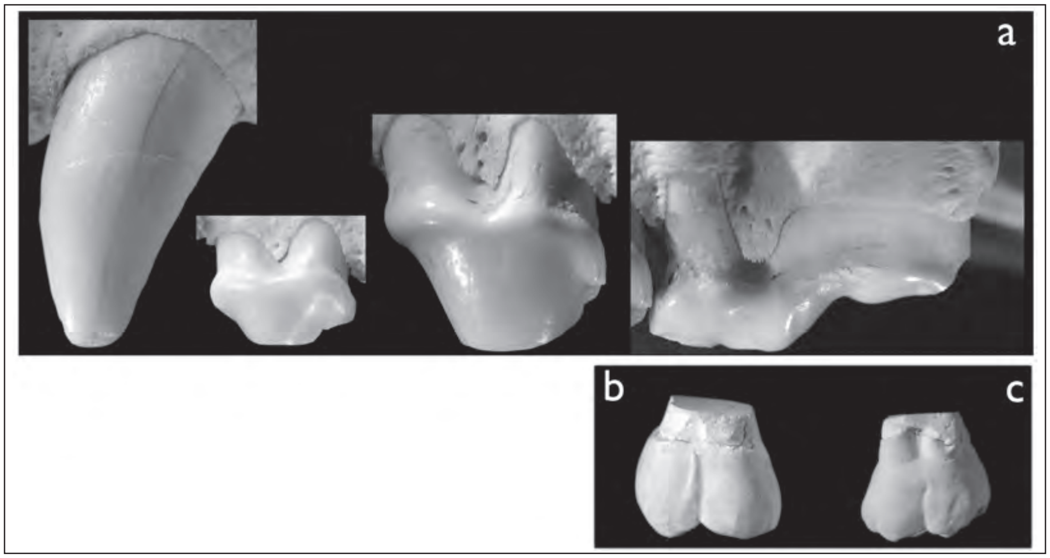

Figure 3. Tooth profiles in different fossil and modern mammals. The Figure illustrates a) an adult modern spotted hyena (U.C. Berkeley MVZ specimen 173762, wild, Narok, Kenya 1981), b) A. boisei *(OH 30), and c) early* Homo *(OH 45) cusp morphologies. It is evident that all three taxa are capable of inducing bone surface modifications that include punctures, pits, and striae such as seen on zooarchaeological remains from localities such as FLK "Zinj."*

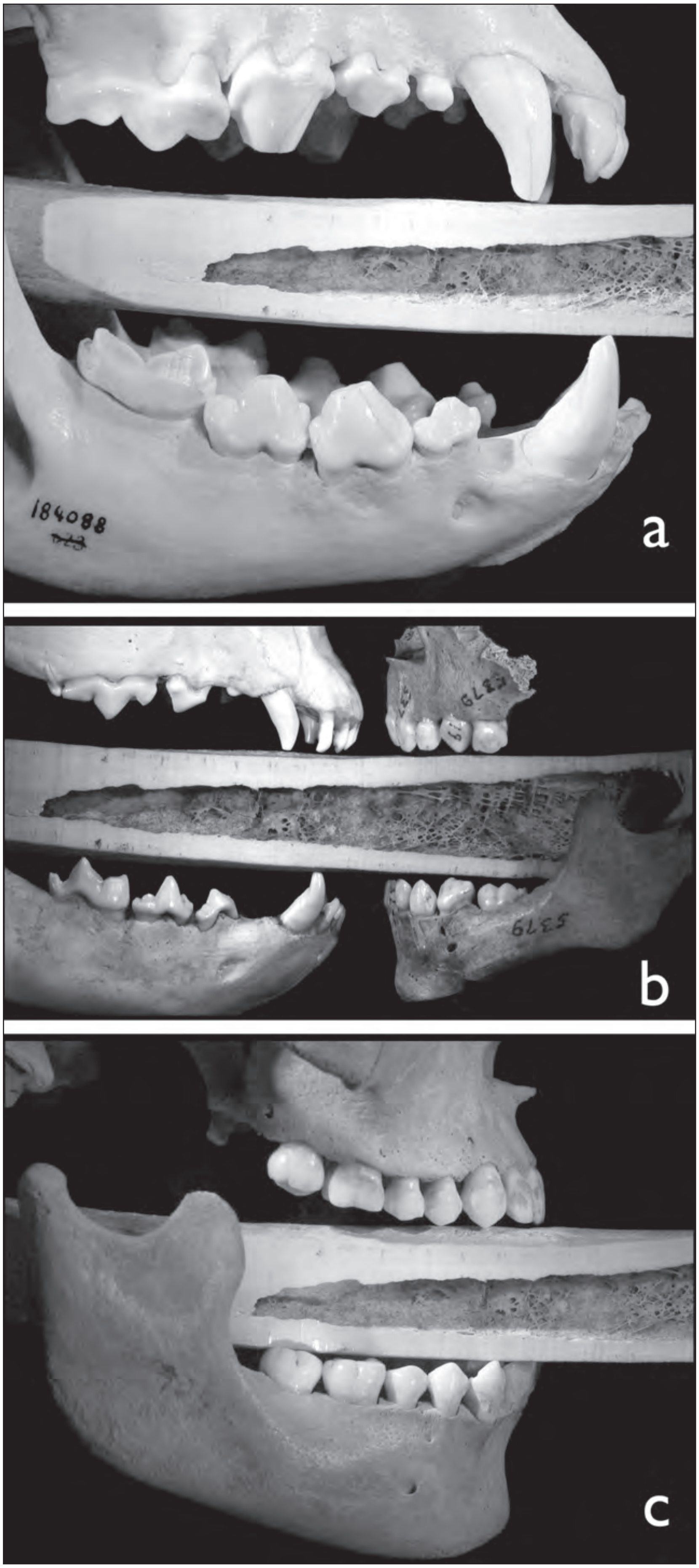

Figure 4. This illustrates the wide range in cusp morphology that would be responsible for bone modifications made by either Crocuta crocuta *(U.C. Berkeley MVZ specimens 173762 and #173772, wild, Narok, Kenya 1981) or Homo sapiens (U.C. Berkeley PAHM specimens, Native American). When both permanent (a, c) and deciduous (b) teeth, in worn and unworn conditions are taken into account, it seems highly unlikely that any particular cusp "signature" will be shown to differentiate these taxa, thus introducing equifinality into the identification of the "chewers" of any zooarchaeological bone assemblage. We do not mean to imply that hominids and hyaenas would both have crushed these midshafts. They are used here only to illustrate the relationship between tooth and bone surfaces.*

of prehistoric cannibalism. White (1992) concludes that it will only be possible in extremely rare cases to identify a toothmark signature that is uniquely attributable to a human agent. Employing a configurational approach, however, he illustrates bone modification that is likely, but not certain, to be the result of human chewing at a prehistoric site in the American Southwest.

CANNIBALISM

A substantial literature featuring various interpretations of human bone assemblages in the American Southwest has been reviewed by White (1992) and Turner and Turner (1999). For decades, Turner argued that cannibalism is indicated for many of these assemblages. In support of this thesis he has developed what he refers to as "the minimal taphonomic signature of cannibalism." White advocates a more functional, anatomical, configurational approach opposed to the checklist approach favored by Turner and Turner. Both authors conclude that the dozens of bone assemblages they review are indicative of cannibalism among the Anasazi, a conclusion bolstered by more recent biochemical work (Marler et al., 2000). After detailed analysis of bone modification and element representation, both Turner and White emphasize the difficulty of distinguishing canid and hominid chewing damage on the human bone assemblages they analyzed.

Turner and Turner (1999) list as one of the items on their cannibalism checklist the following: "Animal gnawing and chewing occurs on only a small proportion of all elements, usually less than 5%. Some gnawing may have been done by humans and/or their dogs." They specify (p. 14): "…we have often been unable to decide whether finger or toe bones were broken by carnivores, humans, or natural mechanical-physical agencies." White's (1992) treatment recognized a pattern of damage to these manual and pedal elements that he concluded, in the context of that assemblage, was strongly suggestive of chewing by the human inhabitants of the Mancos Pueblo.

Using insights into hominid processing of spongy bone that were afforded by the Mancos analysis, we undertook a still unpublished study of the bone assemblages from the Neanderthal site of Krapina in Croatia. This Mousterian site and its contents have been the subject of numerous and varied studies (summarized in Radovčić, 1988, and a more recent review by Patou-Mathis, 1997). A debate over whether cannibalism was practiced among the Neanderthals there and elsewhere has been entertained for over a century (see Defleur et al., 1999 and references therein). We shall not review those arguments, even the ones specific to the Krapina Neanderthal assemblage and its composition. Rather, we wish to draw attention to bone modifications encountered in our study that may represent the kind of unusual evidence which, in rare cases, might make it possible to link actor with effect in a paleoanthropological setting.

The Krapina Neanderthal remains were recovered over a century ago. Unfortunately, the excavation and curatorial techniques employed compromised the behavioral value of the collection. Much of the associated fauna was discarded at the excavation and the smaller component of the bone assemblage was not recovered by sieving. Many of the recovered hominids were extracted in a rough fashion and with coarse provenience. There is abundant evidence of bone damage during recovery and transport. This damage was exacerbated by the fragility of the Krapina osseous material. Better-preserved fragments of Neanderthals have been recovered from cannibal-generated assemblages of limestone caves such as Vindija and Moula-Guercy (Defleur et al., 1999). The sandstone rockshelter of Krapina represented a different depositional and fossilization environment, leading to retention of exquisite surface detail on the bones, but preserving the bone tissue itself as chalky and soft, hence extremely fragile and subject to post-recovery damage. Without preservative, this bone was so soft that pencils used to number it have indented the bone surface. Due to these factors, most of the Krapina hominid bones were coated with variably deep layers of preservatives. This treatment protected the fragile specimens, but left a thick translucent cover that now serves to obscure important details of bone modification on many Krapina specimens.

It is evident from a comprehensive study of the Krapina hominid collection that these Neanderthals were processed intensively with stone tools. Clear stone tool cutmarks and hammer/anvil percussion damage is manifested throughout the collection. In addition, element and element portion preservation resemble those seen in the Mancos collection described by White (1992) (Figure 5). Notions that rock fall might be responsible for this trauma (Trinkaus, 1985) are obviated by the fact that large diameter limb bone shafts are virtually entirely absent (except for percussion-marked splinters), whereas the much more fragile fibular midshafts are intact, but missing their spongy ends.

Figure 6 shows a Krapina Neanderthal fibula shaft, specimen number 230. This specimen lacks a proximal end, but the broken distal end includes a sliver of the articular facet. A series of shallow, paired marks approximately 1.2 mm-wide, cross the shaft perpendicular to its long axis. There are three sets of these marks. The first set, the more proximal one, is 11.5 cm distal to the broken proximal end of the bone. Its short parallel grooves are separated from each other by 5.5 mm (measured between groove centers). The second pair, another 16 cm downshaft, is similar in orientation, morphology, and depth. Its groove centers are separated by 7.5 mm. The third pair, another 26 cm downshaft, is a similar set of shallow grooves with centers separated by 8.5 mm.

There is little or no evidence of diagnostically non-hominid carnivore chewing on the entire Krapina Neanderthal assemblage of over 800 specimens. There is ample evidence of cutmarks made by stone tools, and

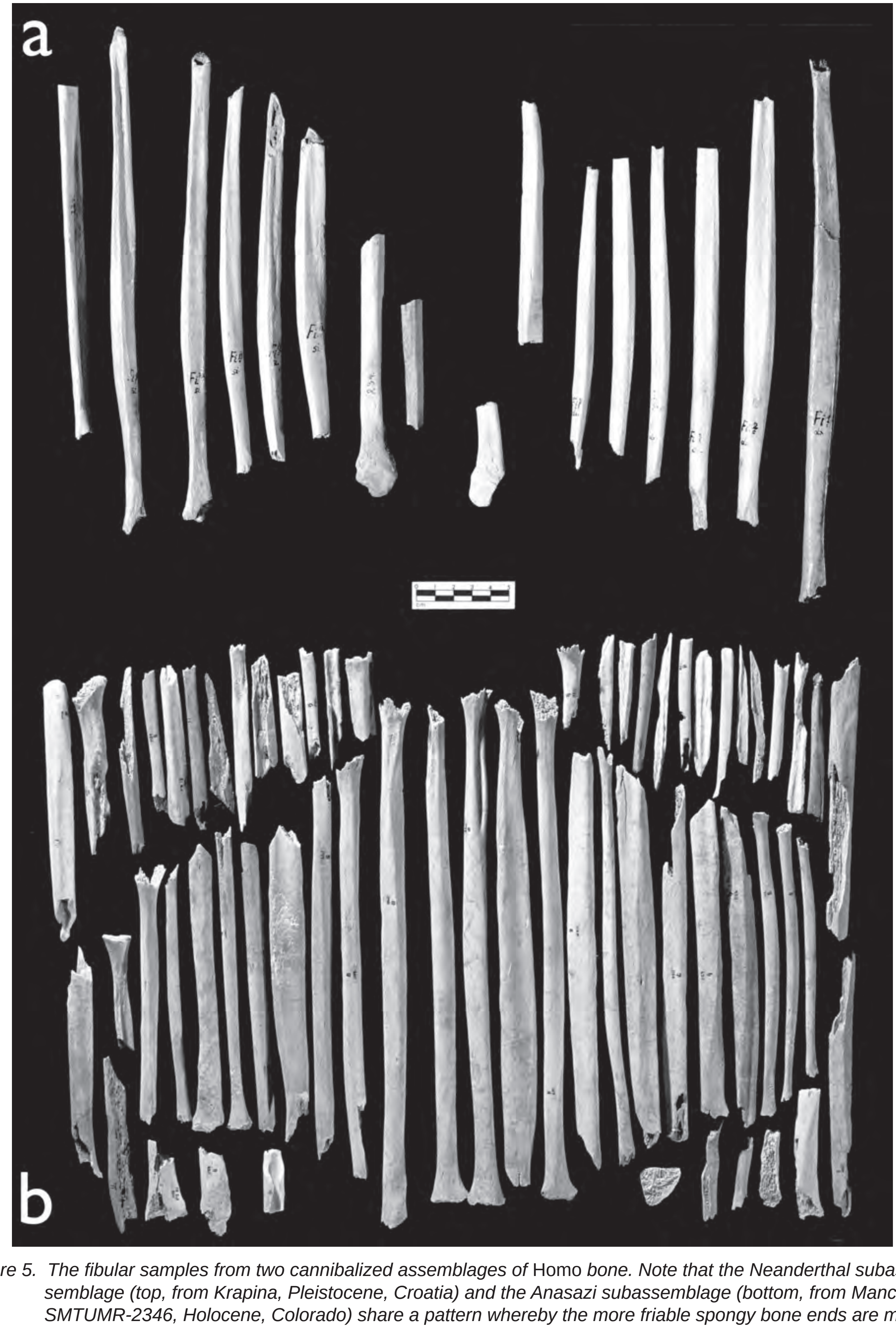

Figure 5. The fibular samples from two cannibalized assemblages of Homo *bone. Note that the Neanderthal subassemblage (top, from Krapina, Pleistocene, Croatia) and the Anasazi subassemblage (bottom, from Mancos SMTUMR-2346, Holocene, Colorado) share a pattern whereby the more friable spongy bone ends are missing whereas the midshafts tend to be preserved intact. This pattern is entirely different for larger-diameter limb bones from this occurrence, such as the tibia and the femur. The latter, larger-marrow capacity bones exhibit clear modification evidence associated with percussion by hammerstone that is inferred to have been directed at marrow procurement. Krapina 230 is third from the left in Figure 5a.*

marrow processing by hammer/anvil technique. Is it possible that the shallow marks seen on the 230 fibula and other specimens like the Krapina 217 tibia of this collection (with similar paired marks as well as cutmarks, peeling, and percussion damage) were made by hominid teeth? Provocatively, the Krapina 49 maxilla, also illustrated in Figure 6b, has a bi-central incisor occlusal edge breadth of 9.0 mm (and an equivalent central-to-lateral incisor breadth), producing an irregular incisal cutting edge that conforms remarkably well to the marks preserved on the fibular shaft. We are not contending that this particular individual used its incisors to remove muscle and/or periosteum from the fibula. We do, however, suggest that this kind of patterning is difficult to explain any other way. How much of the trauma to the Krapina hominid assemblage, or to the hundreds of other collections of zooarchaeological remains, is attributable to chewing by hominid carnivores? This is a research problem that is likely to be difficult to solve given the equifinality predicted above. It may prove that unusual specimens like the Krapina 230 partial fibula will eventually help meet the challenge of identifying hominids among the several carnivorous chewers that might have co-created these assemblages and their characteristics.

Conclusion

From the glacial deposits at Moula-Guercy in the Ardeche to the desert environments of the Afar depression, studies of bone modification yield insight into the prehistoric past. A review of the evidence of hominid chewing as a modifier of zooarchaeological assemblages shows us that Bob Brain's prediction about the teeth of "Stone Age people" (and their ancestors) must no longer be ignored. Brain's early appreciation that early hominid teeth might be expected to impact bone assemblages is but one of many incisive observations in a body of work that has established him as the world's pre-eminent vertebrate taphonomist. May his good science continue to serve as our example, and his curiosity continue to inspire our pursuit of the past.

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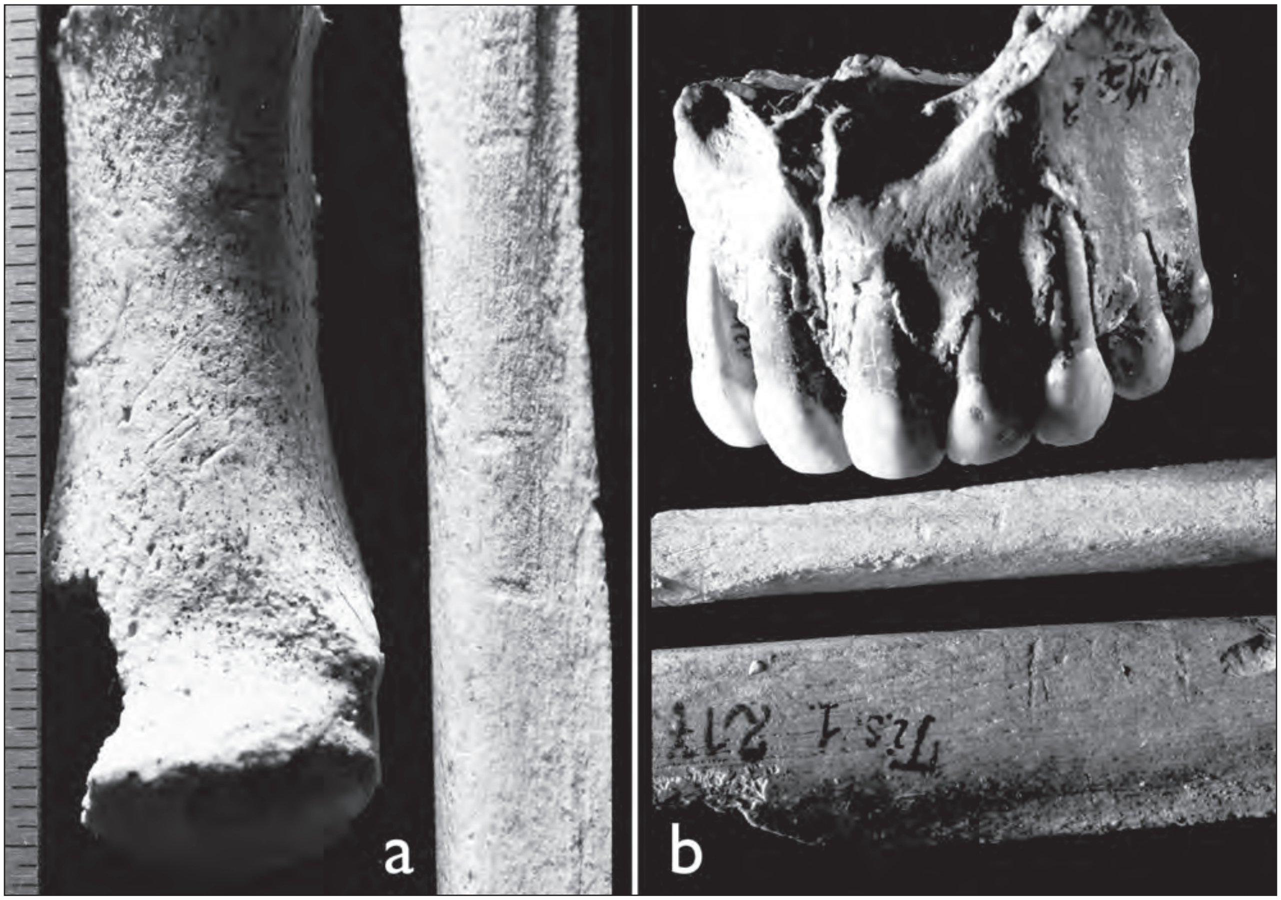

Figure 6. Bone modifications on the Krapina Neanderthals. Figure 6a is a closeup of two specimens, the Krapina 246 first metatarsal with cutmarks on its dorsal surface; and the Krapina 230 fibula with two of the sets of shallow, short, parallel striae described in the text. Figure 6b is a closeup of the latter marks compared to the incisal edge of the Krapina 49 maxillary specimen, which shows that the inter-crown center measures for canines and incisors on this biting edge approximate the features seen on the fibula. This suggests, but does not demonstrate, that these bone modifications are the result of stripping flesh with the front teeth.

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