



## Taphonomy of ungulate ribs and the consumption of meat and bone by 1.2-million-year-old hominins at Olduvai Gorge, Tanzania

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### ABSTRACT

The phenomenon of equifinality complicates behavioral interpretations of faunal assemblages from contexts in which Pleistocene hominins are suspected bone accumulators. Stone tool butchery marks on ungulate fossils are diagnostic of hominin activities, but debate continues over the higher-order implications of butchered bones for the foraging capabilities of hominins. Additionally, tooth marks imparted on bones by hominins overlap in morphology and dimensions with those created by some non-hominin carnivores, further confounding our view of early hominins as meat-eating hunters, scavengers or both. We report on the manual/oral peeling of cortical layers of ungulate ribs as taphonomically diagnostic of hominoid/hominin meat- and bone-eating behavior that indicates access to large herbivore carcasses by hominins at the site of BK, Olduvai. Supporting these inferences, we show that certain types of rib peeling damage are very rare or completely unknown in faunas created by modern carnivores and African porcupines, but common in faunas modified by the butchery and/or consumption activities of modern humans and chimpanzees, during which these hominoids often grasp ribs with their hands, and then used their teeth to peel strips of cortex from raggedly chewed ends of the ribs. Carnivores consume ungulate ribcage tissues soon after kills, so diagnostic traces of hominin butchery/consumption on ribs (i.e., peeling and butchery marks) indicate early access to ungulate carcasses by BK hominins. Tooth marks associated with the peeling and butchery marks are probably hominin-derived, and may indicate that it was not uncommon for our ancestors to use their teeth to strip meat from and to consume portions of ribs. Recognition of rib peeling as a diagnostic signature of hominoid/hominin behavior may also aid the search for pre-archaeological traces of hominin meat-eating.

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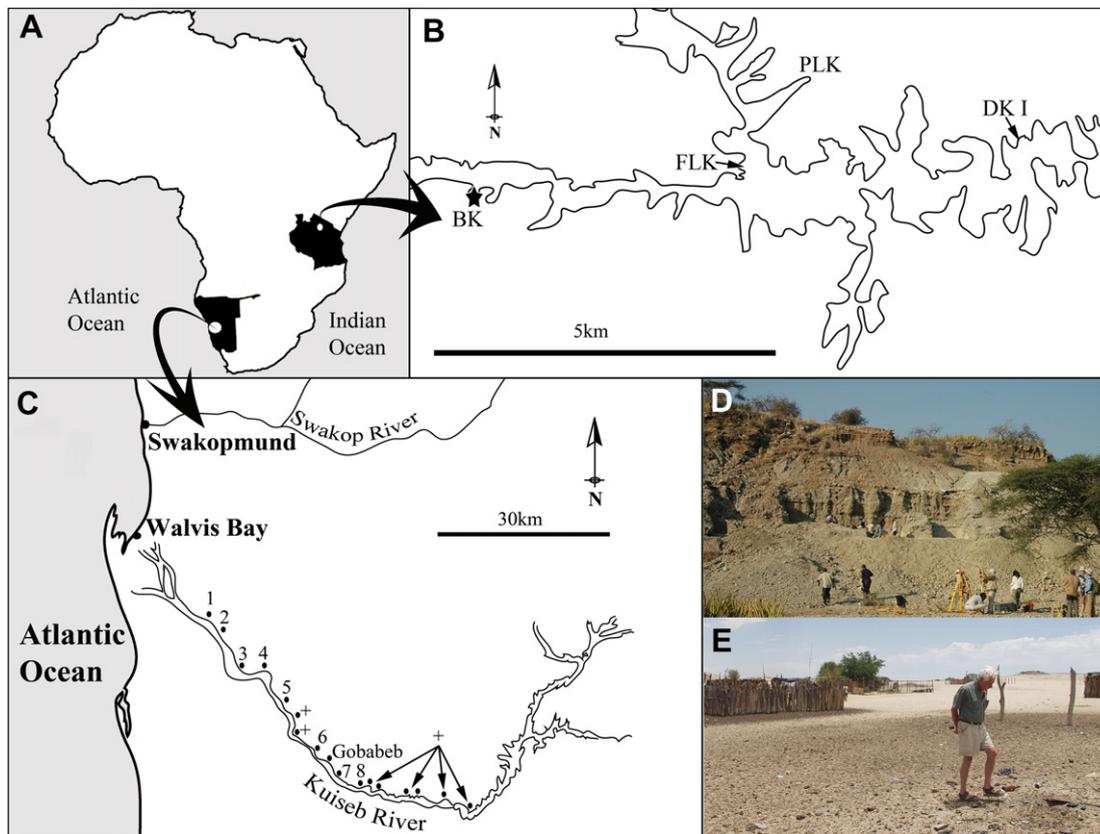
### 1. Introduction

Animal carcass products—skin, meat, brains, viscera, marrow and bone grease—are valuable sources of energy and readily digestible nutrients for consumers equipped to obtain them. Various hypotheses, which link carnivory to hominin brain expansion, social organization and geographic movement into temperate climes

(e.g., Shipman and Walker, 1989; Milton, 2003), emphasize the significance of meat-eating in human evolution. Empirically, some stable carbon isotopic data have been interpreted as evidence of hominin meat-eating (Sponheimer and Lee-Thorp, 1999; Sponheimer et al., 2006), and other studies concluded that early hominin incision and thick postcanine tooth enamel concord, respectively, with “meat tearing and bone crunching” (Szalay, 1975). Further, antemortem step fractures on some early hominin anterior teeth are not inconsistent with damage incurred by spotted hyenas (*Crocuta crocuta*) in the course of chewing bones (White and Toth, 2007). But, it is primarily stone tool butchery marks on ungulate

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**Fig. 1.** Africa with the countries of Tanzania (northeast) and Namibia (southwest) indicated in black; white dots indicate, respectively, the approximate positions of Olduvai Gorge and of the Kuiseb River Valley (A). Plan views of Olduvai Gorge, with some important sites indicated, including BK (star) (B), and the Kuiseb River Valley, with the Khoikhoi villages that supplied the goat rib samples analyzed in this study indicated by numbers (villages that were occupied when bones were collected) and +s (unoccupied villages from which more bones were collected) (C). Informal views of the current excavation at BK (D) and of a Khoikhoi village (E).

fossils from several archaeological sites that demonstrate a significant level of carnivory by early African hominins, starting around 2.6 Ma and continuing through the Pleistocene to current day (Domínguez-Rodrigo and Pickering, 2003; Bunn, 2006).

Here we present data on a newly recognized taphonomic indicator of early hominin carnivory, associated specifically with the consumption of the superficial and intercostal musculature, encased upper viscera, and bones of the ribcages of ungulates at the 1.2 Ma archaeological site of BK (Bell's Korongo), Bed II, Olduvai Gorge, Tanzania (Fig. 1). Ribcage meat and upper viscera rarely survive when non-hominin carnivores consume an ungulate carcass (Blumenschine, 1986; Domínguez-Rodrigo, 1999), so meat-stripping and eviscerating butchery damage (i.e., cut marks placed, respectively, on the dorsal and ventral surfaces of ribs (Nilssen, 2000)) indicates favored feeding access to the thoraxes of these animals by Olduvai Pleistocene hominins. In addition, based on actualistic analogs (discussed below), tooth marks found on these same butchered rib specimens are attributed with high confidence to hominin carcass consumers, constituting the best earliest evidence of this class of hominin bone modification, as well as being direct indications of meat- and bone-eating by early hominins.

## 2. Materials and methods

### 2.1. Modern actualistic samples

We carried-out our zooarchaeological and taphonomic analyses of prehistoric BK faunas within an actualistic framework comprised of the following faunal samples.

#### 2.1.1. Khoikhoi-butchered goat rib samples

In 1966, one of us (CKB) conducted research among a group of 133 Khoikhoi pastoralists living in eight villages in the lower Kuiseb River Valley, Namibia (formerly South-West Africa) (Brain, 1967a,b, 1969, 1981; Jenkins and Brain, 1967) (Fig. 1). Interested in documenting the carcass butchery and consumption practices of the villagers, Brain (1981) supplied the Soutrivier Village with a ~1-year-old male goat (*Capra hircus*). The goat was slaughtered and its carcass was hung in a tree and butchered with metal knives. Brain collected the goat's bones immediately after the Khoikhoi feasted, before the camp's domestic dogs (*Canis lupus familiaris*) and other potential post-human scavengers could intervene. We re-analyzed the rib specimens in this goat bone sample, which is now curated at the Ditsong National Museum of Natural History (DNMNH; formerly the Transvaal Museum), in Pretoria, South Africa. We refer to this sample as the SV (Soutrivier Valley) sample.

Brain also collected other discarded goat bone specimens from the ground surfaces of the eight occupied Kuiseb River villages, as well as from another ten in the area, which were abandoned within historic memory of the local Khoikhoi. These remains, collectively referred to as the GOB sample,<sup>1</sup> also derive from goats butchered by the Khoikhoi, but there was no control to prevent subsequent post-discard intervention by dogs and other scavengers. Brain (1981: 15)

<sup>1</sup> The abbreviation GOB refers to Gobabeb, under which the materials are now curated. The Namib Desert Research Station, where Brain was based during his Khoikhoi research, was renamed The Gobabeb Training and Research Centre in 1998.

**Table 1**  
Modern carnivore-created faunas with a complete lack of classic and general peeling of rib ends. <sup>a,b,c</sup>

Assemblage	Taphonomic agent	Composition of macromammal fauna	Rib NISP
Syokimau	<i>Crocota crocuta</i>	Various large and small Carnivora and Bovidae; <i>Phacochoerus aethiopicus</i> ; <i>Equus burchelli</i> ; <i>Giraffa camelopardalis</i> ; <i>Orycteropus afer</i>	57
KND2	<i>Crocota crocuta</i>	Various large and small Carnivora and Bovidae; <i>Phacochoerus aethiopicus</i> ; <i>Sus scrofa</i> ; <i>Equus asinus</i>	63
Monte Campelo	<i>Canis lupus lupus</i>	<i>Equus caballus</i>	335
Experimental 1	<i>Canis lupus lupus</i>	<i>Phacochoerus aethiopicus</i> ; <i>Capra pyrenaica</i> ; <i>Cervus elaphus</i>	70
Experimental 2	<i>Canis lupus familiaris</i>	<i>Sus scrofa</i>	31
Experimental 3	<i>Vulpes vulpes</i>	<i>Ovis aries</i>	90
Experimental 4	<i>Lycaon pictus</i>	<i>Equus caballus</i>	12
Mapungubwe	<i>Panthera pardus</i>	<i>Papio ursinus</i>	114
Leokwe	<i>Panthera pardus</i> ; <i>Hystrix africaeustralis</i> ; (? <i>Crocota crocuta</i> ; ? <i>Parahyaena brunnea</i> )	Various large and small Carnivora and Bovidae; <i>Phacochoerus aethiopicus</i> ; <i>Equus burchelli</i> ; <i>Loxodonta africana</i> ; <i>Papio ursinus</i> ; <i>Hystrix africaeustralis</i> , <i>Procapra capensis</i>	76

<sup>a</sup> Composition of macromammal fauna lists those taxa that actually or potentially contributed to the rib samples analyzed here; however, for most assemblages, the rib samples are dominated by ungulate specimens. All observations of rib taphonomy were made by the authors. Primary data sources for each assemblage: Syokimau (Egeland et al., 2008); KND2 (Prendergast and Domínguez-Rodrigo, 2008); Monte Campelo (Yravedra et al., 2011); Experimental 1–4, this study; Mapungubwe (Pickering et al., 2011); Leokwe, this study.

<sup>b</sup> See text under **Results** for discussion of classic and general peeling.

<sup>c</sup> NISP = number of identified specimens.

did note, however, that jackals (*Canis* spp.) “were extremely rare in the vicinity of the villages at the time of the study, and spotted hyenas had not been seen in the area for some years. It therefore seems likely that these scavengers do not enter the picture [as taphonomic agents in the immediate vicinity of the Khoikhoi villages].” Brain (1981) reported that this large assemblage, also housed in the DNMNH, includes 174 rib specimens. We were able to find 163 of these specimens in the curated collection, and these specimens comprise the rest of our analyzed sample.<sup>2</sup>

Individual rib specimens in both assemblages were not labeled previously, so, in order to facilitate our analyses, we lightly labeled each with a pencil. The SV goat rib specimens were labeled A–Z; while the rib specimens collected from ground surfaces of the other villages were labeled sequentially, GOB 1–GOB 163.

### 2.1.2. Previously published carnivore-modified faunas

Table 1 summarizes the taxonomic compositions of nine faunal assemblages accumulated and modified by various modern carnivores, including domestic dogs, wolves (*Canis lupus lupus*), African wild dogs (*Lycaon pictus*), fox (*Vulpes vulpes*), spotted hyenas, brown hyenas (*Parahyaena brunnea*) and leopards (*Panthera pardus*); African porcupines (*Hystrix africaeustralis*) also contributed to one of the assemblages. We chose these as comparative assemblages not only because they (1) sample a wide array of bone-modifying agents and because (2) we have personally studied each, but also because each contains a substantial number of ungulate rib specimens (Table 1), which is especially relevant to our study of rib fossils from the BK archaeological levels discussed below. Four of these modern comparative faunas have been previously described and analyzed: the Syokimau spotted hyena-modified assemblage (Egeland et al., 2008); the KND2 spotted hyena-modified assemblage (Prendergast and Domínguez-Rodrigo, 2008); the Monte Campelo wolf-modified assemblage (Yravedra et al., 2011); the Mapungubwe leopard-modified assemblage (Pickering et al., 2011).

### 2.1.3. Previously unpublished carnivore-generated faunas

The other carnivore-generated faunas summarized in Table 1 are newly (and briefly) described here. Experimental assemblage 1 was created by two captive wolves, contained in a 10 ha open-air enclosure located on the Hosquillo Reserve (Cuenca, Spain). During 2008 and 2009, Yravedra fed the wolves the dismembered and fleshed bones of eight warthog (*Phacochoerus aethiopicus*), twelve red deer (*Cervus elaphus*) and four ibex (*Capra pyrenaica*) carcasses. Bones were then collected, cleaned and analyzed by Yravedra.

Experimental assemblage 2 was created by two medium-sized domestic dogs (weights = 21.7 kg and 28.6 kg), which were fed the cooked, mostly defleshed carcasses of two subadult domestic pigs (*Sus scrofa*) on two separate occasions. Pickering then collected, cleaned and analyzed the bones.

Six sheep carcasses were placed by Yravedra, at separate times, around the landscape at Ayllón (Segovia, Spain), where they were fed on by a single free-ranging fox, creating experimental assemblage 3. The sheep carcasses were continuously monitored to assure that the only agent of bone modification was the fox, and not other scavengers. The fox removed some of the sheep bones, but all those remaining after abandonment by the fox were retrieved and analyzed by Yravedra.

Between 1999 and 2010, over the course of 29 individual episodes, Yravedra fed 88 defleshed horse (*Equus caballus*) bones to two African wild dogs, held in captivity on the Cabarceno Reserve (Cantabria, Spain), forming experimental assemblage 3.

The Leokwe assemblage consists of 451 macrovertebrate faunal specimens recovered from a low but horizontally extensive rock shelter in the Mapungubwe National Park (MNP; South Africa), which is utilized as a feeding and refuge site by leopards, Cape porcupines and, probably occasionally, spotted and/or brown hyenas. The MNP is situated on a sedimentary and igneous basement that is part of the Karoo Supergroup, settled within the Tuli Basin. It is a predominantly flat landscape punctuated by large sandstone kopjes. The region receives most of its mean annual rainfall of <500 mm between November and March, which supports a Savannah Biome, including thick growths of mopane trees (*Colophospermum mopane*), abundant baobab trees (*Adansonia digitata*) and scrubby grassveld. Many stretches of the Limpopo River, which serves as the park’s northern boundary, are bounded by dense riparian growth with a closed canopy. The park’s habitat supports abundant large herbivores, including elephants (*Loxodonta africana*), various bovids, giraffes (*Giraffa camelopardalis*) and zebras (*Equus burchelli*), and their predators, including lions (*Panthera leo*), leopards, African wild dogs and hyenas.

<sup>2</sup> Fernández-Jalvo and Andrews (2011: 117) describe their analysis of the bones of “three sheep” (now housed in the DNMNH) “chewed only by [Khoikhoi] people (unknown number) when C.K. Brain was present” on “7 December 1965” and as “described in Brain (1981).” Many of these details are perplexing (see main text), but nonetheless we recognize several of the specimens illustrated in Fernández-Jalvo and Andrews (2011) as deriving from the same samples we report on here.

The Leokwe rock shelter (22° 13' 12", S 29° 21' 53", elevation 566 m) is at the base of the southern termination of a narrow ravine. The ravine is a N–S directed inflection cut into the middle of the north face of an extensive sandstone plateau. To its north, the ravine opens into a broad valley, in which the park's Leokwe Rest Camp is situated.<sup>3</sup> Along a N–S line, it is approximately 235 m from the rest camp to the Leokwe rock shelter, which overlooks a deep but laterally restricted pool of water. As approached from the north, along the bottom of the ravine, a dense thicket conceals the pool and rock shelter opening. Narrow ledges have been eroded in the sandstone rise that flanks the ravine to the east and these show moderate accumulations of bones and some sparse evidence of human cultural activity, including some unremarkable rock art.

All visible bone specimens were collected from the surface of the Leokwe rock shelter in July 2005, as part of Pickering's landscape taphonomy project conducted in the MNP in conjunction with Kathleen Kuman's more extensive paleoanthropological research project. We returned to the rock shelter in July 2006 and collected all visible bone specimens that had accumulated over the year. The samples from both years were combined for the analysis presented here.

#### 2.1.4. Other relevant research

Previous workers have recognized the taphonomic alteration of ribs (White, 1992; Pickering and Wallis, 1997; Fernández-Jalvo and Andrews, 2011). We acknowledge, refer to and build upon their research in this paper.

#### 2.2. BK levels 1–3 ungulate rib samples

The BK site is situated in Bed II of Olduvai Gorge, lying above tuff IID, which is currently dated ~1.2 Ma (Leakey, 1971; Hay, 1976). The site consists of fluvial deposits eroded into tuff IID and its overlying clay and tufa. Olduvai Hominid (OH) 3, the deciduous canine and deciduous molar of a *Paranthropus boisei*, was discovered in BK (Leakey, 1958), and early *Homo* is known from pencontemporaneous contexts (Leakey, 1961). To date, a sequence of eight discrete archaeological levels are recognized in BK. The sample of ungulate rib fossils analyzed here derives from levels 1–3. Previous archaeological investigations of the site converged to characterize it as an area of concentrated activities by early Pleistocene hominins, where an abundance of butchery marks on vertebrate fossils (including those from ungulates ranging in size from diminutive antelopes like *Antidorcas* to the enormous bovid *Pelorovis*) link those fossils causally to large assemblages of Mode I stone tools, and, in turn, to hominin butchery (Leakey, 1971; Monahan, 1996; Egeland, 2007; Egeland and Domínguez-Rodrigo, 2008; Domínguez-Rodrigo et al., 2009). Indeed, the BK zooarchaeological assemblages, along with those from FLK 22 *Zinjanthropus* (Bed I, Olduvai) and ST4 Peninj (Tanzania), constitute the very best evidence of hominin butchery and meat-eating in the early Pleistocene.

### 2.3. Methods

#### 2.3.1. Excavation methods

As part of our new excavations at Olduvai, we opened a 10 × 3 m trench at BK (Domínguez-Rodrigo et al., 2009), which

<sup>3</sup> The Leokwe rock shelter should not be confused with the Iron Age archaeological site complex of Leokwe Hill (Huffman, 1986), which is west of the rock shelter/rest camp. The rock shelter/rest camp is approximately 3 km southeast of the confluence of the Shashe and Limpopo Rivers and about 3 km east of the famous Iron Age site of Mapungubwe Hill.

has since been expanded laterally to a total of 45 m<sup>2</sup>. We used an EDM total station to document the spatial distribution of all excavated paleoanthropological materials and to map the site's complex stratigraphy. We used small hand-held tools to excavate fossil- and artifact-bearing levels and larger tools to remove sterile sections of the sequence. All sediments were sieved thoroughly and every visible fragment of paleoanthropological material was collected.

#### 2.3.2. Laboratory methods

We studied the BK archaeological and modern Khoikhoi rib samples, as well as the modern carnivore- and porcupine-modified faunas, using standard zooarchaeological and taphonomic procedures (see Pickering, 1999). Each rib specimen was inspected under a strong oblique light source with the aid of 10× and higher magnifications, and identification of bone surface modifications was guided by criteria and methods reviewed by Blumenschine et al. (1996).

## 3. Results

### 3.1. Archaeological results

Our excavations reveal that the overall depth of deposit at BK is ~3 m, twice as deep as reported by Leakey (1971). We documented a total of eight clearly differentiated archaeological levels in the site. Levels differ in their densities of paleoanthropological materials, with especially high densities of fossils and artifacts in the uppermost levels, 1 and 2. The ungulate rib samples from these two rich levels, along with that from level 3, are the subject of this report. Including vertically scattered outliers, level 1 is 40 cm deep, but >90% of its included materials are concentrated in the upper 25 cm of the level. Level 2 spans 1 m in depth, but >80% of its materials occur in its upper 20 cm. The depth of level 3 was initially placed at 15 cm (Domínguez-Rodrigo et al., 2009), but subsequent excavation has revealed another 15 cm of fossil and artifact deposition in the level 3 sediments, meaning recurrent use of the site by hominins.

Surface preservation of the fossils recovered from BK levels 1–3 is mostly good-to-excellent (i.e., displaying stage 0 or 1 cortical weathering (Behrensmeyer, 1978)). Some specimens were encrusted with carbonate concretions, but these concretions were easily removed to exposed original bone surfaces. Domínguez-Rodrigo et al. (2009) summarize other relevant supporting data, such as numbers and types of fossils and artifacts recovered.

### 3.2. General condition of the comparative assemblages

The proportion of rib specimens in weathering stage 0 or 1 (i.e., good-to-excellent preservation) ranges from 85% to 100% in the eleven modern comparative assemblages. Those rare specimens that show more intensive longitudinal cortical cracking or flaking of outer lamellae (weathering stage 2 or greater) were eliminated from our analyses.

### 3.3. Comparative taphonomic results

Table 2 summarizes relevant zooarchaeological and taphonomic data on the ungulate rib samples from levels 1–3 of BK, showing a consistent pattern of stone tool cut marks, mammalian tooth marks and peeling of cortical bone layers. This same combination of taphonomic traces characterizes the two samples of butchered goat ribs collected by Brain from the villages of modern Khoikhoi pastoralists living in the Kuiseb River Valley (Tables 2 and 3; see also Appendices 1, 2). Because of definitive hominin involvement in

**Table 2**Modified ungulate rib number of identified specimens (NISP) in the modern Khoikhoi village and archaeological BK samples. <sup>a,b</sup>

Damage constellation NISP	Khoikhoi villages		BK archaeological levels		
	SV	GOB	1	2	3
None	0	5 (3.1%)	0	0	0
Fracture	1 (3.4%)	8 (4.9%)	44 (57.9%)	41 (65.7%)	41 (53.9%)
Fracture + peel	1 (3.4%)	10 (6.1%)	4 (5.3%)	3 (4.8%)	7 (9.2%)
Tooth	0	3 (1.8%)	0	0	0
Tooth + fracture	0	5 (3.1%)	6 (7.9%)	7 (11.1%)	5 (6.6%)
Tooth + peel	0	4 (2.5%)	0	0	0
Tooth + fracture + peel	1 (3.4%)	34 (20.9%)	3 (3.9%)	3 (4.8%)	2 (2.6%)
Tool	13 (44.8%)	4 (2.5%)	0	0	0
Tool + fracture	1 (3.4%)	14 (8.6%)	11 (14.5%)	7 (11.1%)	20 (26.3%)
Tool + fracture + peel	4 (13.8%)	23 (14.1%)	4 (5.3%)	1 (1.6%)	1 (1.3%)
Tool + tooth	3 (10.3%)	1 (0.6%)	0	0	0
Tool + tooth + fracture	0	5 (3.1%)	3 (3.9%)	0	0
Tool + tooth + peel	4 (13.8%)	9 (5.5%)	0	0	0
Tool + tooth + fracture + peel	1 (3.4%)	38 (23.3%)	1 (1.3%)	1 (1.6%)	0
<b>Total</b>	<b>29 (100.0 %)</b>	<b>163 (100 %)</b>	<b>76 (100.0 %)</b>	<b>63 (100.0 %)</b>	<b>76 (100.0 %)</b>

<sup>a</sup> Abbreviations: SV = Soutrivier Village; GOB = Gobabeb, combined villages; BK = Bell's Korongo; NISP = number of identified specimens; tool = presence of any combination of chopping into or off of rib head and/or tubercle and/or other cut and chop marks; tooth = presence of any combination of crenulation and/or other type(s) of tooth mark(s); fracture = fractured end; peel = only classic or general peeling (see text for discussion of peeling types).

<sup>b</sup> Codes: None = a complete, undamaged rib; Fracture = a rib with at least one fractured end, but no other damage; Fracture + peel = a rib with at least one fractured end that is also peeled, but which is otherwise undamaged; Tooth = a complete rib with some type(s) of tooth damage, but no other damage; Tooth + fracture = a rib with tooth damage of some type(s) and at least one fractured end, but no other damage; Tooth + peel = a rib with tooth damage of some type(s) and peeling that emanates from a crenulated edge and *not* a fractured end; Tooth + fracture + peel = a rib with some type(s) of tooth damage and at least one fractured end that is also peeled; Tool = a complete rib with cut and/or chop marks but no other damage; Tool + fracture = a rib with cut and/or chop marks and at least one fractured end, but no other damage; Tool + fracture + peel = a rib with cut and/or chop marks and at least one fractured end that is also peeled; Tool + tooth = a complete rib with tooth damage of some type(s) and cut and/or chop marks, but no other damage; Tool + tooth + fracture = a rib with tooth damage of some type(s), cut and/or chop marks and at least one fractured end, but no other damage; Tool + tooth + peel = a rib with tooth damage of some type(s), cut and/or chop marks and peeling that emanates from a crenulated edge and *not* a fractured end; Tool + tooth + fracture + peel = a rib with tooth damage of some type(s), cut and/or chop marks and at least one fractured end that is also peeled.

both the modern Kuiseb River Valley and archaeological BK contexts—established by direct observation in the former and by the recovery of abundant stone artifacts in the latter (Leakey, 1971; de la Torre, 2004)—the presence of defleshing cut marks on bones in both samples was not unexpected. More surprising is the significant presence of tooth marks in all three rib samples, especially in the SV sample, which was formed and modified in the complete absence of nonhuman carnivores (Fig. 2). Thus, all the tooth marks in the SV sample were created by humans. In addition, the SV sample contains rib specimens, the ends of which were fractured and/or chewed by the Khoikhoi and then subsequently peeled.

### 3.3.1. Types of rib cortical peeling

Three types of cortical peeling damage are observed in both the SV and GOB samples.

- (i) *Classic peeling* is the type described by White (1992: 140–142): “imagine bending...a small fresh twig...Stripped of its bark, the twig can bend until it snaps. When the wood is fresh, however, the two pieces will tend to remain attached by fibrous connection until ‘peeled’ apart. The peeling apart of the two pieces leaves a distinctive pattern (a roughened surface with parallel grooves left as the two halves are pulled apart). This pattern observed on wood is very similar to the same phenomenon on fractured and peeled fresh bone.” In other words, with classic peeling, layer(s) of lamella(e) is/are missing in strip(s) from the rib's dorsal, ventral or both cortices (Fig. 3A). Classic peeling can occur at various points along a rib's length but is commonly observed at the sternal termination of short fragments of the vertebral ends of ribs. Much of the classic peeling White (1992: 224) documented in the sample of human (*H. sapiens*) ribs from a cannibalized Anasazi assemblage (Mancos, USA) occurs on the dorsal

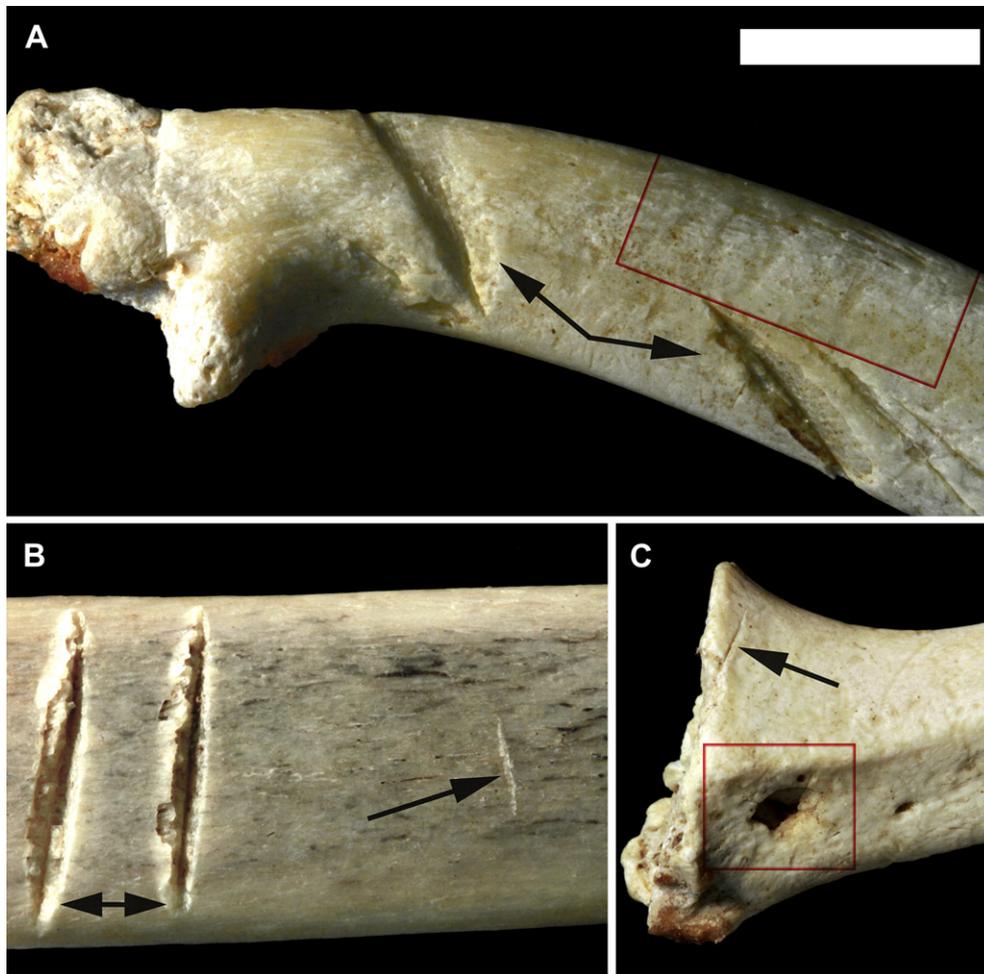
surfaces of vertebral fragments of ribs, and is attributed to “rib slabs held together by fascia and intercostal musculature [being] levered back against the transverse processes of the thoracic vertebrae.” Brain (1981) also observed this type of butchery action at SV when villagers removed ribs from goat carcasses, and it also accords with that that we have observed among other modern foragers, like the Hadza of northern Tanzania (for examples from other ethnographic contexts, see Yellen, 1977; Binford, 1984). Given the consistency of this butchery pattern, we presume the same actions account, as well, for many if not most of the fractures on and peeling of the sternal terminations of short vertebral fragments of ribs in the GOB sample.

- (ii) With *general peeling*, an area of the whole dorsal or ventral cortex of a rib is peeled backed for some length, revealing the internal trabeculae of the rib (Fig. 3B). In the SV and GOB samples, general peeling sometimes emanates from the ax- or knife-chopped terminus of a rib end. In other cases, it emanates from the sternal ends of nearly complete ribs,

**Table 3**Bone surface modification frequencies by anatomical aspect (ventral or dorsal cortex) in the Soutrivier Village (SV) and Gobabeb (GOB) goat rib samples. <sup>a</sup>

Modification	SV		GOB	
	Ventral	Dorsal	Ventral	Dorsal
Cut/chop mark	45 (38.1%)	65 (55.1%)	177 (77.6%)	51 (22.4%)
Tooth pit	1 (50.0%)	1 (50.0%)	31 (44.3%)	39 (55.7%)
Tooth score	3 (37.5%)	5 (62.5%)	57 (58.8%)	40 (41.2%)
Tooth puncture	0	0	2 (40.0%)	3 (60.0%)
Comprehensive tooth marks	4 (40.0%)	6 (60.0%)	90 (52.3%)	82 (47.7%)

<sup>a</sup> Raw values indicate number of individual marks. Counts do not include crenulation, only individual marks. In addition, one of the SV specimens presents an area of diffuse chewing damage in which individual marks cannot be discerned nor counted; 18 of the GOB specimens are likewise affected by diffuse, unquantifiable chewing damage.



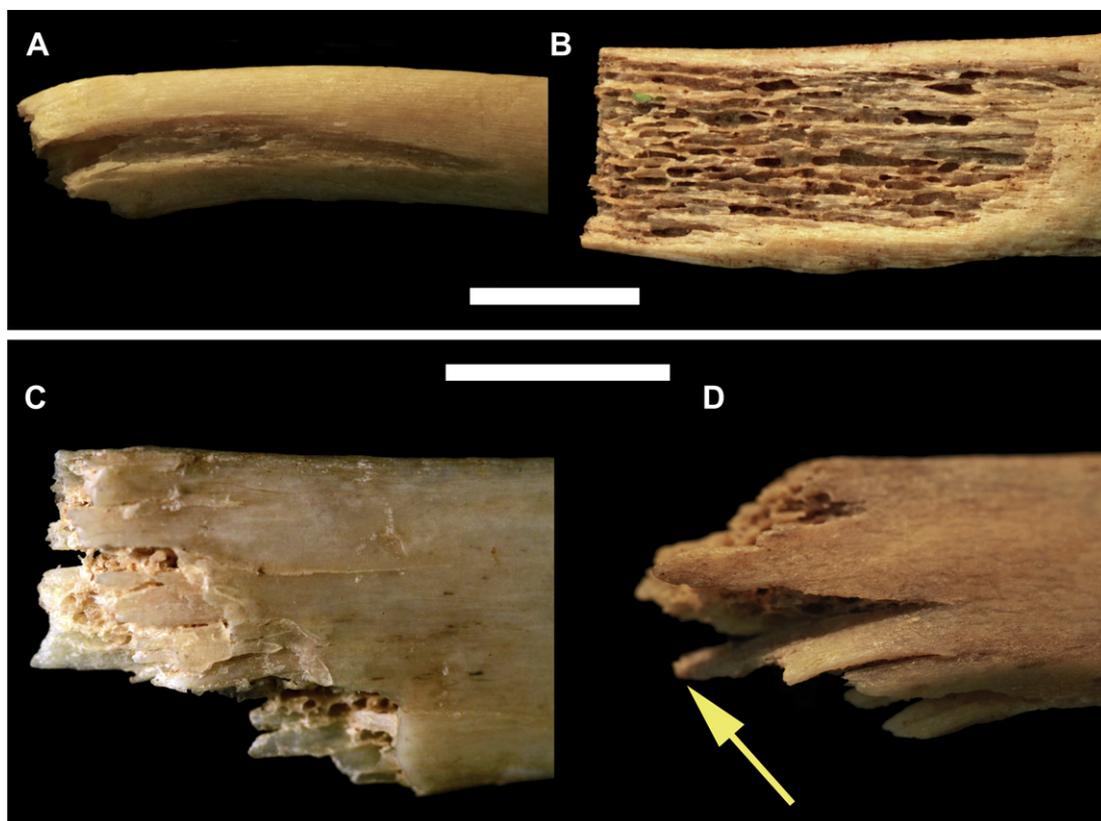
**Fig. 2.** Ribs of goats butchered and eaten by Khoikhoi pastoralists preserve co-occurring butchery and tooth marks. The rib in (A) is shown in dorsal view, with human tooth scores outlined in the box and heavy chop marks made by a metal cutting tool indicated by arrows. Image (B) shows two deep chop marks inflicted by a metal tool (indicated by the double arrow) and a sub-parallel human tooth score (indicated by a single arrow) on the ventral surface of a rib, and image (C) shows the dorsal surface of a different rib with a metal knife cut mark (arrow) and a human tooth puncture (outlined in the box) highlighted. Bar scale = 1 cm.

where humans (or possibly other agents, but see below) chewed the rib ends minimally into ragged surfaces and then presumably used their incisors to grip flanges of cortex and pull those flanges back toward the vertebral ends of ribs. The resultant rib specimens are thus peeled at their sternal ends but nonetheless lack true sternal fracture edges. Pickering and Wallis (1997) observed that captive chimpanzees (*Pan troglodytes*) engaged in the action described above to create general peeling damage on cattle (*Bos taurus*) ribs that they were fed.

General peeling can also be initiated by another type of chewing. Based on their experiments in which modern European subjects chewed ribs, as well as on their analysis of some of the same Khoikhoi-derived samples that we analyzed, Fernández-Jalvo and Andrews (2011: 121) found that humans using their premolars and molars to chew ribs “produced a characteristic shape, bending the [end of a rib] relative to the long axes [*sic*, axis] of the bone, sometimes leaving a curved shape at the very end of the rib...The bones are bent by pushing up or down on the ends of the bone, using the hands and holding the ends between the upper and lower cheek teeth, the necessity of which results from the difficulties that flat-cusped molar teeth have in

crushing hard bone tissues. Bending is characteristic of the [Khoikhoi] ethnological chewed bone collection. Some of our European [experimental bone-chewers] commented that this is the easiest way to break the bone and suck the marrow.” Fernández-Jalvo and Andrews are describing a system in which the teeth and jaws of a human act essentially as a vise on the one end of a rib, with the hand acting to ratchet the opposite end. The ratcheting of ribs in such a manner can separate the ventral and dorsal cortices of the rib, which then splay apart at the formed bend. Fernández-Jalvo and Andrews are correct that ratcheting-induced bending damage is common on the ends of rib specimens in the Khoikhoi-generated samples; there are several specimens with tooth-“mashed” ends (Fig. 3C). However, for a bent rib to qualify as truly peeled, a taphonomic agent must use its teeth (probably the incisors, based on our observations of chimpanzees and humans) or, less likely (and only in the case of hominoids), its fingers, to grip a bent, craniocaudally wide strip of bone and pull it back from the affected edge, peeling away that strip (Fig. 3D).

(iii) *Incipient peeling* is a type of peeling where a strip(s) of lamella(e) is/are only partially peeled back against the rib shaft, not fully removed from the specimen (Fig. 4A). This

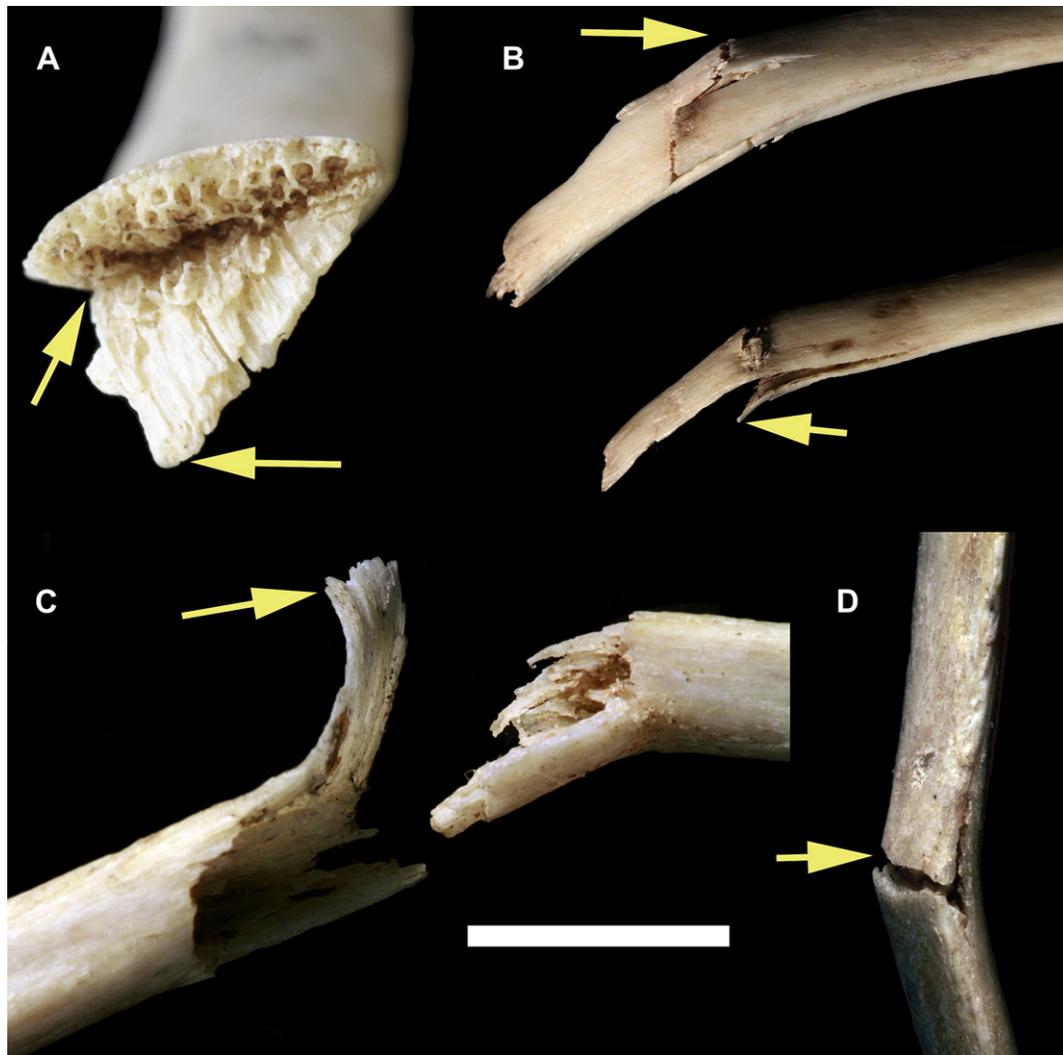


**Fig. 3.** Classic peeling on the dorsal surface of a goat rib butchered and eaten by Khoikhoi pastoralists. The peeling, which is defined by the removal of several layers of lamellae but which does not invade the bone cortex so deeply as to expose the internal trabeculae, emanates from the chewed sternal end (left of the image) of the rib (A). General peeling on the dorsal surface of a goat rib butchered and eaten by Khoikhoi pastoralists. The peeling, which is defined by the removal of the entire dorsal cortex of the rib, exposing internal trabeculae for a measurable distance, emanates from the ax-chopped sternal end (left of image) of the rib (B). Goat rib (dorsal view) with a sternal end chewed intensively by a Khoikhoi pastoralist, resulting in a heavily “tooth-mashed,” ragged end (note also the numerous individual tooth scores and pits and chewing-induced microcracks interspersed and to the right of the mashed area) (C). Bent flange of cortical bone (indicated by arrow) at the mashed sternal end of a goat rib chewed by a Khoikhoi pastoralist; it is this type of flange that can be gripped by the teeth or fingers and then pulled back against the rib, resulting in peeling damage (D). Bar scales each = 1 cm.

type of peeling is equivalent to the bent rib ends described by Fernández-Jalvo and Andrews (2011) (see Discussion above). Importantly, incipient peeling is not always the consequence of intentional chewing for extraction of intra-rib nutrients. For example, it is a fairly common feature of a sample of rib specimens (occurs on 24 of 114 total specimens; 21.1%) that were snapped from their sternal articulations, and then sometimes levered back toward the spine, by wild leopards as they fed on baboon (*Papio ursinus*) carcasses under natural field conditions (Pickering et al., 2011). The incipiently peeled rib fragments in that leopard-generated assemblage are not tooth-marked and thus we infer that the incipient peeling is simply a result of bone breakage and the subsequent tensile recoil of lamellae, which originates at the fracture edge where the thin dorsal and ventral cortices of the affected specimens are now separated (Fig. 4B). Fig. 4C illustrates two rib specimens from the GOB goat rib sample, refit at a midshaft snap, on which incipient peeling is apparent. An early stage of the same phenomenon is observed as incomplete midshaft breaks on some baboon ribs in the leopard-created assemblage (Pickering et al., 2011), as well as on some specimens in the GOB goat rib sample (Fig. 4D). We have even observed incipient peeling on the broken ribs of mounted human skeletons and on other laboratory specimens.

Because incipient peeling is as much a consequence of intrinsic rib structure as it is of applied taphonomic forces, we argue that this type of damage is less behaviorally informative than are classic and general peeling. We note further that behaviorally informative, classic and general peeling damage is *completely absent* in carnivore-generated faunas for which we have relevant data (Table 1), although Gary Haynes (personal communication, 2012) has observed general peeling on the end of a rib of a subadult elephant that was killed and eaten by lions and then scavenged by spotted hyenas (Fig. 5). In contrast to the complete absence or extreme rarity of classic and general peeling in carnivore-created assemblages, both types of peeling are relatively common on ribs in hominoid-created faunas, including: the Khoikhoi SV goat rib sample (11 classically or generally peeled specimens of a total rib number of identified specimens, or NISP, of 29 [37.9%]; Table 2 and Appendix 1); a sample of cattle ribs chewed by captive chimpanzees (13 classically or generally peeled specimens of a total rib NISP of 44 [29.5%] (Pickering and Wallis, 1997)); numerous cannibalized Native American bone assemblages from the western USA (White, 1992; Turner and Turner, 1999; Novak and Kollman, 2000).

Thus, classic and general rib peeling is highly diagnostic of hominoid- (and more specifically hominin-) generated faunas, especially when observed in assemblages with other categories of hominin-diagnostic bone modifications, including stone tool



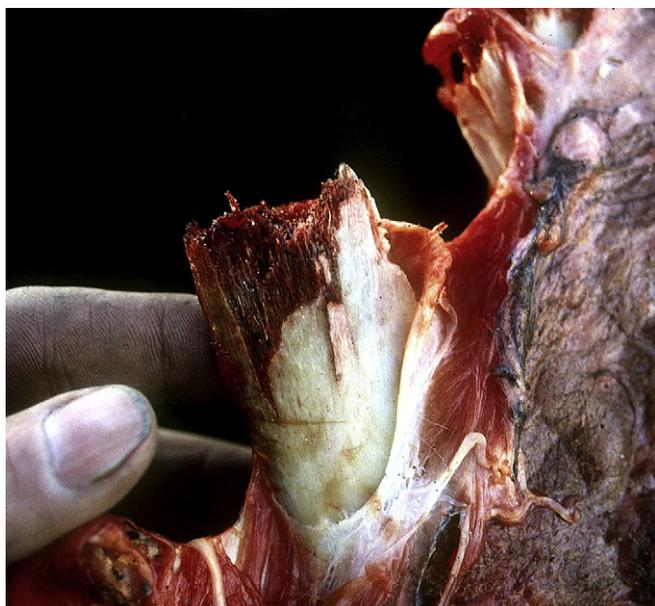
**Fig. 4.** Sternal end-on view of a goat rib (ventral surface at top of image, dorsal at bottom) butchered by Khoikhoi pastoralists showing incipient peeling where the ventral and dorsal cortices are recoiling away from each other (arrow on left of image) points to a dark transverse line that represents the internal contact of the ventral and dorsal cortices; arrow at bottom points to severe downward recoil of dorsal cortex (A). The neck and proximal shafts of two baboon ribs that are incipiently peeled as the result of leopard feeding activities; leopards levered the ribs back against the baboon spine, resulting in snaps through the rib necks and incipient peeling placed sternally to those snaps (arrows) (B). Refitting specimens from a single goat rib butchered by Khoikhoi pastoralists; note the incipient peeling (arrow) (C). A baboon rib chewed by a leopard shows an incomplete midshaft snap (arrow), the first stage in the creation of incipient peeling (D). Bar scale = 1 cm.

butchery marks. Of particular relevance in Table 1 are data on the Leokwe (South Africa) faunal assemblage, which, based on direct observations and taphonomic analyses, was formed by multiple taphonomic actors, none of them hominin. The complete lack of classic and general rib peeling in the Leokwe fauna is in stark contrast to the commonness of these types of peeling in the modern GOB assemblage, which was also formed by multiple taphonomic actors, but, unlike Leokwe had humans as its main agents of formation and modification. We argue that this distinction accounts for the absence of classic and general rib peeling in the Leokwe sample and its abundance in the GOB assemblage.

In terms of the frequencies of specimens that preserve cut marks and/or classic and general peeling damage (the three definitive diagnostic traces of hominin behavior preserved in the Khoikhoi-derived and BK assemblages), all samples are comparable when taking into account the much greater degree of rib fragmentation in the fossil samples. Only 31% (9 of 29 rib

specimens) of the SV sample is fragmented (and even this “fragmentation” is minimal, since all fragmented pieces can be refit to form complete ribs), while 84.1% (137 of 163 specimens) of the GOB sample and 100% of each of the BK fossil samples is fragmented (Table 2, combined data rows 2, 3, 5, 7, 9, 10, 12, 14). Inversely, the SV and GOB samples have, respectively, the highest (SV: 28 of 29 total specimens; 96.6%) and second highest (GOB: 142 of 163 total specimens; 87.1%) number of specimens bearing cut marks and/or classic and general peeling, while only 34.2% (level 1 NISP = 26), 23.8% (level 2 NISP = 15) and 39.4% (level 3 NISP = 30) of the heavily fragmented BK samples are comprised of specimens that preserve cut marks and/or classic and general peeling (Table 2, combined data rows 3, 6–14).

The low frequencies of cut marks in the two modern (and least extensively fragmented of all five) assemblages (with a mean of 3.7 individual cut marks per specimen in the SV sample and a mean of 1.3 per specimen in the GOB sample (Table 3)) suggest that cut marks are inflicted only very rarely on ribs when modern humans



**Fig. 5.** We thank Gary Haynes for alerting us to this rare instance of general peeling damage that was created by lions or spotted hyenas on the sternal end of the rib of a subadult elephant that was killed, eaten and scavenged at Shabi Shabi (Hwange National Park, Zimbabwe). That the rib shaft was protruding from but still partially embedded in the elephant's thoracic musculature and skin probably acted to stabilize it so that when it was snapped its dorsal surface was then broken back and off by the feeding actions of carnivores. Photograph courtesy of Gary Haynes.

have absolute and unfettered control of carcasses on which they feed. Sediment compaction and other long-term diagenetic processes, which affected the BK assemblages but not the SV and GOB samples, resulted in such extensive fragmentation of the fossil samples that none of those samples preserves a single complete rib. If the modern samples had suffered similar degrees of post-depositional attrition (resulting in many more smaller, secondarily fragmented pieces), we predict that both would, like the BK assemblages, show a much depressed frequency of specimens that preserve cut marks and/or classic and general peeling.

#### 4. Discussion

Based on our observations of various bone-modifying agents, we suspect the reason that hominoid/hominin-generated faunas have significant incidences of classic and general rib peeling and carnivore-generated faunas have almost none is that, unlike carnivores, a hominoid/hominin can easily hold a rib that he is chewing with his hands. Generally, when a bone chewing carnivore (like a hyena or dog) gnaws on disarticulated, meatless bones, it focuses mostly on those skeletal elements with straighter long axes than has a typical rib, which is instead curved in its longest dimension. The hyena or dog can easily hold the epiphysis of a relatively straight long limb bone (like an ungulate humerus) between its front paws, with the bone's shaft and opposite epiphysis propped up toward its mouth (it is harder for the carnivore to stabilize a curved, disarticulated rib in the same way). Once the long limb bone is so positioned, the carnivore will use its carnassials to gnaw the exposed epiphysis of the bone. This kind of focused chewing creates furrows in the bone's epiphysis and, with enough time, can lead to the complete destruction of the epiphysis. The carnivore might then continue to chew its way down the bone's metaphysis and diaphysis, perhaps creating ragged flanges of cortex that can be eventually stripped back, creating peeling damage at the chewed margin of the bone.

Based on uniformitarian principles, bone gnawing carnivores of the early Pleistocene would have behaved similarly to modern hyenas and dogs with regard to bone chewing. A parallel conclusion, based on data presented here, is that early Pleistocene hominins, as exemplified by those who contributed to the formation of the Olduvai BK faunas, behaved like modern humans when they butchered, peeled and consumed the edible tissues of ungulate ribcages. Cut and chop marks on ungulate ribs from three archaeological levels at BK, along with high confidence, hominin-induced classic and general peeling and tooth marks on ribs, indicates early, favorable access to carcasses by hominins (Fig. 6). The axial skeletons of ungulates are laden with meat and also encase copious upper viscera, soft tissues usually consumed early in the feeding sequences of carnivores that have first access to those carcasses (Blumenshine, 1986; Domínguez-Rodrigo, 1999).

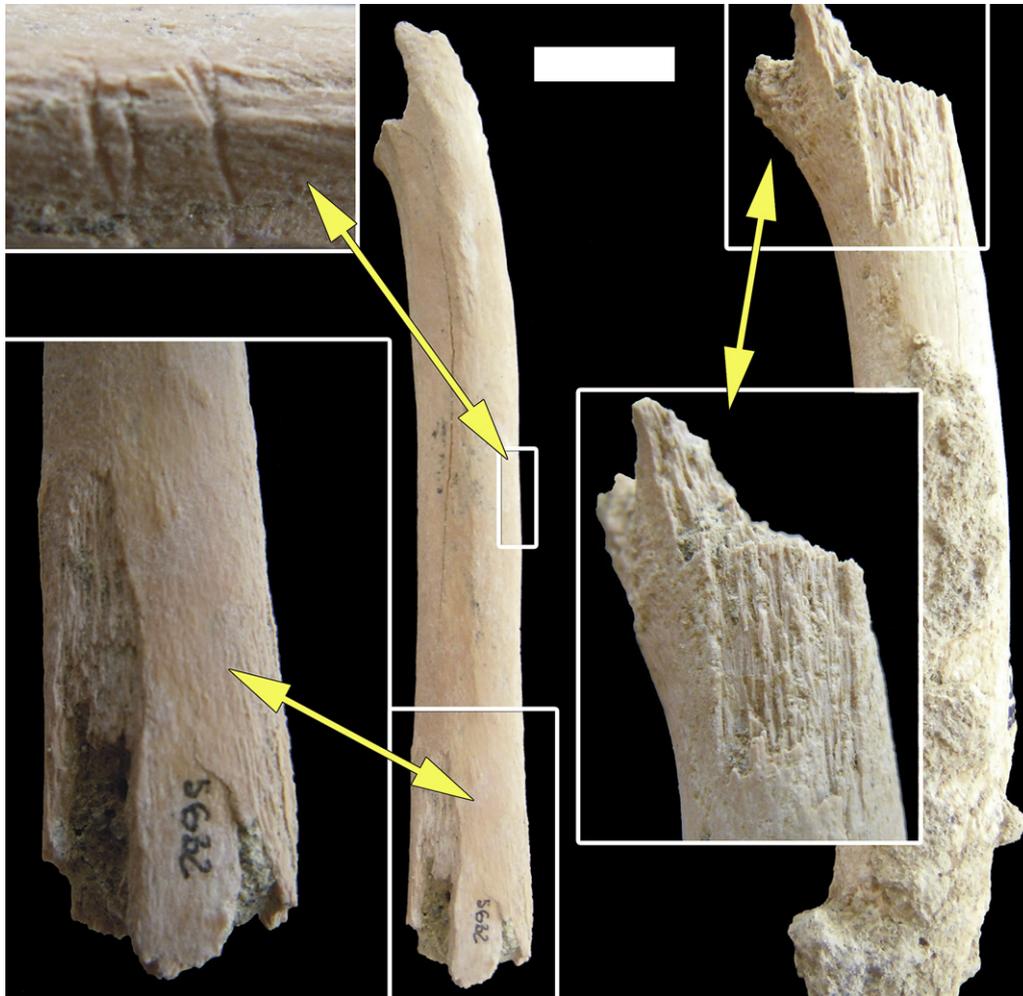
Because classic and general rib peeling appear to be diagnostic of hominoid/hominin behavior, their occurrences in the BK faunas on some rib specimens that also exhibit tooth marks (and especially on those with tooth marks *and* cut marks) suggest that those tooth marks were probably created by hominins (non-hominin hominoids are not known from Olduvai). In turn, this indicates intensive exploitation of these carcass resources, including not just defleshing of musculature but also direct bone chewing by hominins. In addition, because of their association with classic and general rib peeling, the BK rib tooth marks stand as the strongest candidates for the earliest known Pleistocene hominin tooth marks on bones.<sup>4</sup>

Because two hominin species have been recovered from Bed II Olduvai (Leakey, 1958, 1961), it would be incautious to implicate one or the other as the sole tooth-marker of the BK ungulate ribs. However, recent stable carbon isotope evidence (Cerling et al., 2011), corroborated by data on occlusal microwear (Ungar et al., 2008, 2012), indicates that *P. boisei* was probably a committed  $C_4$  forage-eater (but see, Constantino et al., 2010), whereas early *Homo* shows none of the extreme diet-linked craniodental specializations of *P. boisei*. The genus *Homo* also persists, in continued association with stone cutting tools and butchered animal bones, beyond the extinction of *P. boisei*. Taken together, these facts suggest that if *Homo* was not the exclusive impartor of the butchery marks, classic and general peeling and tooth marks on the BK ungulate ribs, then it was at least one of the imparters. Using their anterior teeth to regularly strip meat from bones (probably assisted by tools) might, in part, account for the spatulate, moderately large maxillary incisors of early *Homo*, as compared to the diminutive anterior dentition of sympatric *P. boisei*. The upper incisors of *Homo* are also broader mesiodistally than are those of its presumptive ancestors (Tobias, 1991), and late early, as well as middle, Pleistocene *Homo* evince high rates of incisal wear (Bermúdez de Castro et al., 2003).<sup>5</sup>

Additionally, even though the occlusal topography and microwear patterns of early *Homo* postcanine teeth suggest "limited consumption of extremely fracture resistant items [like the bones

<sup>4</sup> Others argue for hominin tooth marks on Middle Paleolithic *H. neanderthalensis* bones from Krapina, Croatia (White and Toth, 2007), and on an ungulate metapodial from the South African Middle Stone Age site of Klais River Mouth (Binford, 1984).

<sup>5</sup> Indeed, the tooth marks and crenulation on lagomorph, bird and tortoise (*Testudo hermanni*) bones from the Middle Paleolithic site of Bolomor (Spain)—which are associated with butchery marks and peeling damage (Blasco, 2008, 2011; Blasco and Fernández Peris, 2009)—bear such strong morphological similarities to those created experimentally by modern humans on rabbit (*Oryctolagus cuniculus*) bones (Lloveras et al., 2009) that they are securely attributable to hominins.



**Fig. 6.** Dorsal surfaces of two large ungulate ribs (vertebral ends toward top of image) excavated from BK level 3. Classic peeling is evident on both ribs (at sternal end of rib on left, at vertebral end of rib on right). The rib on the left also shows hominin tooth marks (box in upper left of image). Bar scale = 1 cm.

of large vertebrates], at least by the time the food reached the back teeth,” compared to extant great apes, early *Homo* still had relatively thick enamel (Ungar et al., 2012). *Homo erectus*, in particular, has dispersion of microwear texture complexity values similar to *Paranthropus robustus* (Ungar et al., 2012), the South African hominin inferred to have been a hard-object feeder. More, from a modern Western perspective, we may overestimate the challenges of consuming uncooked bone; “The dentitions of all [early Pleistocene hominins] were occluded under the force of a powerful masticatory apparatus...Crushing of nutritious spongy bone under a thin cortex would have been easy for any of these creatures” (White and Toth, 2007: 288). The ungulate rib taphonomy data, showing an array of nutrient extraction damage—from cut marks to classic and general peeling to tooth marks—seem to confirm this assertion.

Finally, there two ancillary but not inconsequential implications of the findings presented here. First, results of important taphonomic meta-analyses suggest that each ungulate skeletal part belongs to either a high- or low-survival element set (Cleghorn and Marean, 2007). Bones in the high-survival element set are comprised predominantly of thick cortical bone and thus better resist density-mediated taphonomic processes than do the thinner-walled and highly cancellous bones that make-up the low-survival element set. Based on these differing properties of the bones in the two sets, it is argued that skeletal elements in the high-survival set are the most useful for investigating behavioral processes of the past (Cleghorn and Marean, 2007). This is compelling logic, but

most archaeofaunas—even those less than exceptionally preserved—contain at least some bone specimens that derive from the low-survival element set. Further, beyond the important behavioral implications of their mere presence in a fauna, many of these low-survival specimens preserve bone surface modifications that are also behaviorally relevant. Outram (2001) and Bunn (2007) provide thoughtful discussions of these topics as they apply, respectively, to ungulate scapulae and vertebrae, which both occupy the low-survival element set. Data presented here expand the discussion initiated by Outram and Bunn to a consideration of ribs, another category of bone in the low-survival element set. Ungulate ribs are critical components of the very earliest zooarchaeological record. Among the oldest known fossils butchered by simple stone tools is a cut-marked bovid rib from the 2.6 Ma Kada Gona site of EG 13 (Afar, Ethiopia) (Domínguez-Rodrigo et al., 2005).<sup>6</sup> From the more recent early Pleistocene, in addition to BK (discussed above), FLK 22 *Zinjanthropus* (Bunn, 1982; Bunn and Kroll, 1986; Domínguez-Rodrigo et al., 2010a), ST4 Peninj (Domínguez-Rodrigo et al., 2010b), various sites in the vicinity of Lake Turkana (Kenya) (Bunn, 1982, 1997) and Swartkrans (South Africa) (Brain, 1993; Pickering et al., 2008), among others, have all

<sup>6</sup> McPherron et al. (2010) assert that an even more ancient, ~3.4 Ma ungulate rib fossil from Dikika (Ethiopia) also shows butchery marks, but this claim is contested (Domínguez-Rodrigo et al., 2010c, 2011, 2012).

yielded abundant, taphonomically informative samples of ungulate rib specimens in archaeological contexts.

Last, the finding that classic and general rib peeling is diagnostic of hominoid behavior could be harnessed in the quest for the earliest indications of hominin meat-eating. This type of bone damage should be visible in properly preserved faunas that were created by hominins using a hypothetical pre-Oldowan stone tool technology and in even non-artifactual contexts.

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## Appendix

### Appendix 1

Soutrivier Valley (SV) goat rib assemblage bone damage matrix. <sup>a</sup>

SV specimen	Vertebral articular chop	Vertebral fracture	Vertebral peel	Vertebral crenulation	Midshaft incipient fracture	Sternal fracture	Sternal peel	Sternal crenulation	Butchery marks	Tooth marks
A	X								X	X
B	X								X	
C	X						X		X	
D	X								X	
E	X						X		X	
F	X								X	X
G	X								X	X
H	X					X	X		X	
I	X								X	
J (i)						X	X		X	X
J (ii)		X	X						X	X
K									X	
L									X	
M		X	X						X	X
N	X						X		X	
O	X						X		X	
P									X	
Q (i)						X			X	
Q (ii)		X	X						X	
R (i)						X			X	X
R (ii)		X					X		X	
S	X									
T	X								X	
U	X								X	
V	X								X	
W	X								X	
X	X								X	
Y	X								X	
Z		X	X						X	

<sup>a</sup> Heading codes: **vertebral articular chop** = ax or knife chopping detachment of rib head and/or tubercle; **vertebral fracture** = non-chopping or indeterminate fracture of rib distal to rib head, tubercle and angle but proximal to rib midshaft point; **vertebral peel** = presence of any type of non-incipient peeling damage emanating from fracture edge as defined by a vertebral fracture; **vertebral crenulation** = ragged chewing along fracture edge as defined by a vertebral fracture; **midshaft incipient fracture**; incomplete break of rib at midshaft; **sternal fracture** = fracture of rib proximal to anatomical sternal end but distal to rib midshaft point; **sternal peel** = presence of any type of non-incipient peeling damage emanating from fracture edge as defined by a sternal fracture; **sternal crenulation** = ragged chewing along fracture edge defined by a sternal fracture or from intact sternal end of rib; **butchery marks** = presence of any additional, non-vertebral articular chop cut and/or chop marks; **tooth marks** = presence of any non-crenulation tooth marks, such as pits, scores and punctures.

### Appendix 2

Gobabeb (GOB) goat rib assemblage bone damage matrix. <sup>a</sup>

GOB specimen	Vertebral articular chop	Vertebral fracture	Vertebral peel	Vertebral crenulation	Midshaft incipient fracture	Sternal fracture	Sternal peel	Sternal crenulation	Butchery marks	Tooth marks
1	X					X	X		X	X
2				X		X	X			X
3	X					X	X			
4	X					X	X			
5		X	X			X			X	X
6	X					X			X	
7	X					X	X			X

(continued on next page)

## Appendix 2 (continued)

GOB specimen	Vertebral articular chop	Vertebral fracture	Vertebral peel	Vertebral crenulation	Midshaft incipient fracture	Sternal fracture	Sternal peel	Sternal crenulation	Butchery marks	Tooth marks
8	X					X	X		X	X
9		X	X			X	X			X
10				X		X	X		X	X
11	X					X	X		X	
12		X				X	X		X	
13		X	X			X	X		X	
14				X		X	X		X	X
15						X	X		X	
16						X	X		X	
17	X					X	X		X	
18	X					X				
19										
20						X	X		X	
21		X	X						X	
22						X	X		X	X
23	X					X	X			X
24						X			X	
25		X	X			X				X
26				X		X	X			X
27	X					X	X		X	
28						X	X		X	
29									X	
30		X				X	X		X	X
31		X				X				X
32						X			X	
33						X	X		X	
34	X					X				
35						X	X		X	
36						X	X			
37						X	X		X	X
38	X		X	X		X	X	X	X	X
39				X			X	X		X
40										
41				X			X	X		
42				X		X	X			X
43				X			X	X		X
44			X	X		X	X	X	X	X
45		X				X	X		X	X
46		X	X			X	X			
47		X	X			X	X			X
48	X					X	X			X
49		X				X	X			X
50		X	X			X	X			
51				X		X				X
52			X	X		X	X			
53			X	X		X	X		X	X
54		X				X				
55						X			X	
56	X					X			X	
57			X	X		X	X			
58	X					X	X		X	
59				X		X	X			
60		X	X			X	X			X
61		X								
62		X	X			X	X			
63									X	X
64		X	X			X	X			X
65		X				X	X		X	
66		X	X			X	X		X	
67		X	X						X	
68		X				X	X		X	
69	X					X	X		X	X
70						X				
71		X				X	X		X	
72						X			X	
73		X				X	X		X	X
74	X						X		X	X
75	X					X	X			X
76		X	X			X	X			
77	X					X				X
78				X			X	X		X
79		X				X	X			
80	X					X	X		X	X
81		X				X			X	X

## Appendix 2 (continued)

GOB specimen	Vertebral articular chop	Vertebral fracture	Vertebral peel	Vertebral crenulation	Midshaft incipient fracture	Sternal fracture	Sternal peel	Sternal crenulation	Butchery marks	Tooth marks
82	X			X		X				X
83	X					X	X			
84		X				X				
85		X				X			X	
86	X					X	X			X
87				X		X	X	X	X	X
88				X		X	X			
89	X					X	X			X
90		X	X			X	X			X
91										
92		X				X				
93		X				X	X		X	
94								X		
95		X	X			X	X			X
96		X	X			X	X			
97	X					X			X	
98		X	X			X	X		X	
99		X	X			X	X			X
100										
101		X				X	X			
102		X	X			X	X			
103		X				X	X		X	X
104		X	X			X	X			X
105						X				X
106		X				X				
107		X	X			X				X
108			X	X					X	X
109						X	X		X	X
110	X					X				X
111		X	X			X	X			
112	X								X	
113			X	X		X	X			X
114		X	X			X	X			
115			X	X		X	X		X	
116						X	X		X	
117	X									
118		X	X			X	X		X	X
119						X	X			
120	X								X	
121						X	X		X	
122	X					X			X	
123		X				X	X		X	
124	X					X	X			
125		X	X			X	X			X
126				X					X	
127	X					X	X			
128										
129	X					X	X			
130	X					X	X		X	X
131		X	X				X	X		
132		X	X			X	X		X	X
133		X				X	X			
134				X		X	X			X
135		X	X			X	X			X
136	X					X			X	
137		X	X			X			X	
138		X				X				
139		X	X				X		X	
140	X					X	X			X
141				X		X	X			X
142		X					X		X	
143	X					X	X		X	X
144				X		X	X		X	
145		X	X			X	X			X
146		X				X			X	X
147		X	X			X				
148		X	X							
149		X				X			X	
150		X	X							
151		X	X							
152		X	X			X	X		X	
153	X					X	X			X
154		X							X	

(continued on next page)

## Appendix 2 (continued)

GOB specimen	Vertebral articular chop	Vertebral fracture	Vertebral peel	Vertebral crenulation	Midshaft incipient fracture	Sternal fracture	Sternal peel	Sternal crenulation	Butchery marks	Tooth marks
155		X	X			X				
156		X	X			X			X	X
157		X					X			X
158				X		X				X
159		X				X	X		X	X
160		X	X			X	X		X	
161		X				X				X
162				X				X		X
163						X				

<sup>a</sup> Heading codes: **vertebral articular chop** = ax or knife chopping detachment of rib head and/or tubercle; **vertebral fracture** = non-chopping or indeterminate fracture of rib distal to rib head, tubercle and angle but proximal to rib midshaft point; **vertebral peel** = presence of any type of non-incipient peeling damage emanating from fracture edge as defined by a vertebral fracture; **vertebral crenulation** = ragged chewing along fracture edge as defined by a vertebral fracture; **midshaft incipient fracture**; incomplete break of rib at midshaft; **sternal fracture** = fracture of rib proximal to anatomical sternal end but distal to rib midshaft point; **sternal peel** = presence of any type of non-incipient peeling damage emanating from fracture edge as defined by a sternal fracture; **sternal crenulation** = ragged chewing along fracture edge defined by a sternal fracture or from intact sternal end of rib; **butchery marks** = presence of any additional, non-vertebral articular chop cut and/or chop marks; **tooth marks** = presence of any non-crenulation tooth marks, such as pits, scores and punctures.

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