Journal of Human Evolution 57 (2009) 260–283

Contents lists available at ScienceDirect

Journal of Human Evolution

journal homepage: www.elsevier.com/locate/jhevol

Unraveling hominin behavior at another anthropogenic site from Olduvai Gorge (Tanzania): new archaeological and taphonomic research at BK, Upper Bed II

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ARTICLE INFO

Article history:
Received 12 August 2008
Accepted 26 April 2009

Keywords:
Olduvai Gorge
Meat-eating
Cut marks
Percussion marks
Taphonomy
Lower Pleistocene archaeology
Hunting
Scavenging

ABSTRACT

New archaeological excavations and research at BK, Upper Bed II (Olduvai Gorge, Tanzania) have yielded a rich and unbiased collection of fossil bones. These new excavations show that BK is a stratified deposit formed in a riverine setting close to an alluvial plain. The present taphonomic study reveals the second-largest collection of hominin-modified bones from Olduvai, with abundant cut marks found on most of the anatomical areas preserved. Meat and marrow exploitation is reconstructed using the taphonomic signatures left on the bones by hominins. Highly cut-marked long limb shafts, especially those of upper limb bones, suggest that hominins at BK were actively engaged in acquiring small and middle-sized animals using strategies other than passive scavenging. The exploitation of large-sized game (*Pelorovis*) by Lower Pleistocene hominins, as suggested by previous researchers, is supported by the present study.

Introduction

Recent taphonomic re-analyses of all the Olduvai Bed I sites have shown that with the exception of FLK Zinj, all sites were palimpsests with minimal hominin input in the accumulation and modification of archaeofaunas (Domínguez-Rodrigo et al., 2007). An extension of this analysis to all Bed II sites has also shown that, with the exception of BK, all faunal assemblages were either too poorly preserved to evaluate, or accumulated by biotic agents other than hominins (Egeland and Domínguez-Rodrigo, 2008). A taphonomic review of all sites older than 1 Ma (Domínguez-Rodrigo, 2008a) stresses the scarcity of sites of anthropogenic origin in all of the Lower Pleistocene, in which a functional link between stone tools and fauna can be established. Therefore, archaeologists are faced with the following questions: were the butchery and meat-consumption behaviors inferred from sites such as FLK Zinj marginal or common in Plio-Pleistocene hominins? Is there any other Plio-Pleistocene site where the faunal assemblage could be identified as completely (or mostly) accumulated and modified by hominins?

The fact that many sites are now understood to be palimpsests underscores the need to increase samples of faunal assemblages that might be attributed to hominin behavior, and thoroughly analyze them with modern taphonomic techniques so as to understand hominin behavioral variability. A recent study of the BK faunal collection stored at the National Museums of Kenya (Nairobi) showed some affinities with FLK Zinj that deserved further scrutinizing (Egeland, 2007; Egeland and Domínguez-Rodrigo, 2008). This prompted our re-investigation of the BK site.

The BK (Bell's Korongo) site was found in 1935 at the top of Bed II in lateral connection with a tuff (Tuff IID) that was dated to 1.2 Ma (Leakey, 1971; Hay, 1976). The clays, silts, and sands that contain the archaeological deposit represent the fillings of a riverine system responsible for the erosion of Tuff IID, which the site overlies. Several visits, minor excavations, and selective surface and *in situ* collections were carried out in 1952, 1953, 1955, 1957, and eventually in an extensive and less selective excavation in 1963. These excavations (totaling 10 trenches) revealed a very rich assemblage of stone tools and bones amounting to over 6,800 lithic

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doi:10.1016/j.jhevol.2009.04.006

pieces, including 652 whole flakes, 721 tools, and almost 400 pieces of utilized material (Leakey, 1971). This assemblage was classified as belonging to the Developed Oldowan B complex (Leakey, 1971, 1976). Approximately 2,900 faunal remains were also unearthed, of which Bovidae, Equidae, and Suidae are the most abundant groups. Pieces of ostrich eggshell were unusually plentiful.

A striking feature of this site was the presence of a minimum of 24 individuals of the large buffalo-like bovid *Pelorovis*, found in the same area of the old excavation (Trench 5-6-7 set). One of them was found virtually complete and lying in a silt deposit, which had been interpreted as a swamp. Leakey (1971) offered this discovery as proof of the butchering of *Pelorovis* carcasses by hominins, possibly after having forcefully driven them into the swamp. If true, this would be the oldest recorded episode of megafaunal hunting and butchery. The site was initially interpreted as a hominin camp situated adjacent to a river or swamp, with part of its contents having been washed into the river channel (Leakey, 1971).

The bone assemblage excavated by Leakey (1971) was first taphonomically analyzed by Monahan (1996), and then by Egeland (2007). Monahan reported a low frequency of hominin-imparted marks in the assemblage (<5%), including 46 cut-marked and 49 percussion-marked specimens out of a NISP of 1078, which is substantially lower than the frequency of tooth-marked specimens (7.7%) he identified. He interpreted the site as a hominin-carnivore scenario, in which hominins butchered carcasses prior to the intervention of carnivores, although he remarked on the paucity of hominin-imparted marks when compared to either human-carnivore experimental scenarios or to other anthropogenic sites such as FLK Zinj.

Egeland (2007) also reported a low frequency of tooth-marked specimens in the assemblage (<10%) and a similarly low number of cut-marked fragments ($n = 33$). Egeland documented a lower number of percussion-marked specimens ($n = 19$) than Monahan. Despite this, he also interpreted BK as a hominin-carnivore assemblage, the result of hominins repeatedly butchering carcasses in the same spot. Egeland (2007) stressed that, despite the strong hominin signal, the great depth of the deposits cautioned against interpreting the entire assemblage as hominin-derived. In Egeland's (2007) analysis, it became clear that the taphonomic properties of the assemblage differed from those documented in most Bed I and Bed II sites (Domínguez-Rodrigo et al., 2007; Egeland and Domínguez-Rodrigo, 2008). The anthropogenic factor seemed to have been more important–as initially reported by Monahan (1996)–than at the other Bed II sites, which instead represent natural palimpsests. This key difference warrants further investigation of the faunal remains from BK.

The present research introduces the first unbiased bone assemblage (where all specimens irrespective of preservation and size were retrieved) from BK, with clear contextual information and a thorough taphonomic analysis. Leakey's (1971) original interpretation of the site will also be re-evaluated in light of this recent research. This is the first publication of renewed archaeological research in the form of large-scale excavation at any of the Olduvai sites excavated by M. Leakey almost 50 years ago.

The excavation of BK

In the summer of 2006, an international team headed by M. Domínguez-Rodrigo and A. Mabulla resumed excavations at BK. One 10 m × 3 m trench was opened between Leakey's Trench 4 and the Trench 5-6-7 set (Fig. 1a, b). Trench 4 contained the remains of what was once an open-air exhibit created by Leakey, showing a dense concentration of bones and stone tools. More than 90% of the original exhibit, along with the building constructed to shelter the archaeological assemblage, had disappeared (Fig. 1c, d). The remaining fossils were slowly eroding out of their context and sliding down the outcrop. We decided to salvage these valuable fossils to enable their study. Therefore, these fossils were plotted, collected, and analyzed in the same fashion as the fossils derived from the excavation of our trench.

Leakey's original excavations lacked crucial information regarding the vertical distribution of materials at BK. Since it has been shown that most of the Bed I sites are palimpsests (Domínguez-Rodrigo et al., 2007), having both vertical and horizontal control of the materials in any new excavation is essential. Thus, recent excavations used a total station to document the spatial distribution of all excavated materials and map the intricate stratigraphy of the site. Small hand tools were utilized during the excavation of the fossiliferous levels and larger tools were used in the sterile sections of the sequence. Sediments were completely sieved, with every visible fragment collected. These procedures retrieved more than 6,000 bones and 1,500 flaked stone specimens; this is many more faunal remains than Leakey recovered in all her trenches combined, suggesting the selective collection of materials by prior excavators, given that our trench was situated in between the trenches excavated by Leakey (1971).

Leakey reported that the average thickness of the archaeological deposit at BK was 5 ft (~1.5 m). In our excavation, the overall depth of deposit was documented as 3 m, almost twice that previously reported (Fig. 2). Furthermore, three clearly differentiated archaeological levels were detected during excavation. A possible fourth level, represented by Leakey's exhibit level in the adjacent trench, did not occur in our trench because it rests on the main body of the channel at the exhibit level. If we consider this a separate level, then we can initially distinguish four archaeological levels. We do not know if the exhibit level is different from what we identified as the *Pelorovis* level in our trench. It certainly occurs above the *Pelorovis* level, and the channel sediments in which it is embedded barely contain any fossils in the excavated part of our trench. For the sake of objectivity, and given that it was not located in our trench, we keep the exhibit level separate in the present analysis.

The bottom level (BK4), with vertically scattered materials, corresponds to Leakey's *Pelorovis* level. Faunal materials in this level were more intensively affected by carbonation and soil humidity, in contrast to the well preserved materials in the overlying levels (see below). The carbonation consisted of carbonate concretions adhered to fossils and sediments, which reacted to acid. The origin is unknown, but they could result from carbonate deposited by lake transgressive cycles after burial, which resulted in the cementation of the soil. It is difficult to classify Leakey's BK collection according to these newly-documented levels, but it likely comprises the lowermost two–the *Pelorovis* level (BK4) and the exhibit level (BK3)–since they span 1.5 m in depth as reported by Leakey (1971) and have similar taphonomic properties as those levels documented by our field research. Furthermore, both levels contain a high density of faunal remains belonging to animals larger than Bunn's (1982) size 3, especially in BK3 where they comprise almost one-third of the specimens retrieved.

Each of the three levels we excavated showed a different density of materials. This is not the result of excavating different dimensions in each level, with the lower section of the stratigraphy having a larger area exposed, since even though smaller areas could potentially be excavated higher up in the sequence (given that the trench was cut into a steep slope; see Fig. 3), our excavation strategy involved creating steps, which exposed similar areas in all the excavated levels. We created a step immediately after reaching the level where Leakey's exhibit level (BK3) should have appeared, where we found the main body of the channel instead. This makes the excavated levels–given that BK1 and BK2 were stratigraphically

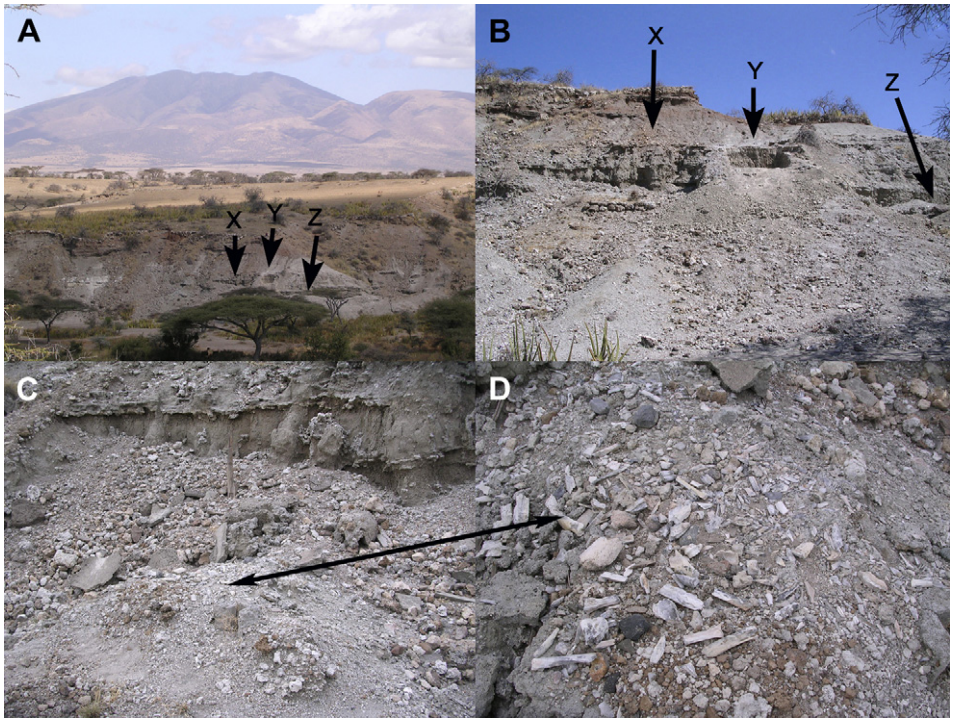

Figure 1. A: Location of BK in the side gorge at Olduvai, and Leakey's 1950s trenches corresponding to the *Pelorovis* level (Z, Trench 5-6-7 set), the 1963 excavations (X, Trench 4), and our trench in between (Y). B: Detail of these trenches. C: Remnants of Leakey's exhibit level (BK3). D: Detail of the exhibit level and the remaining fossils that are eroding away.

close–very similar in size: about 12 m^2. Therefore, variation in material density is not related to size differences of the excavated areas of each level. One striking feature is the much higher overall density of fossil bones in the uppermost levels (BK1 and BK2). Despite this density, it is surprising that these levels do not seem to represent the main body of the deposit, as described by Leakey (1971). This is most likely because they did not contain large-sized tools or "identifiable" fossils, like those documented in the exhibit level (BK3) and the *Pelorovis* level (BK4), which can also be observed in the Leakey collection. We documented only four small epiphyseal fragments in BK1 and BK2, among hundreds of long limb shafts and, to a lesser extent, axial and cranial remains.

Documenting the vertical distribution of materials is crucial to the understanding of the site formation process. BK1 is 40 cm deep if we include vertically scattered outliers, but >90% of the materials are concentrated in 25 cm of depth. BK2 spans 1 m, but >80% of the materials occur in the uppermost 20 cm. BK3 (corresponding to the exhibit level) was only documented as 15 cm in depth; however, excavation did not proceed underneath the fossil accumulation to document its vertical extent given that BK3 is documented in Leakey's Trench 4 and not in our trench. However, the impression this level gives is similar to that of BK1 and BK2: most of the archaeological materials appear concentrated in 20–15 cm horizons with a lower number of fossils vertically dispersed in the section between. BK4 shows a different distribution of materials with lower densities of fossils and artifacts, which occur vertically scattered through a depth of almost 1 m.

The excavated area is too small to discern any patterns in the horizontal distribution of materials. If vertical distribution is ignored, then one can discuss the meaning of horizontal associations between fossils and artifacts, as reported by Leakey (1971) for most Bed I and Bed II sites. However, Leakey's horizontal associations may be dubious since archaeological items with different depths and depositional histories may have been considered one horizontal "level." Even if BK1 and BK2 seem to be vertically discrete, each of them is probably the result of more than one depositional episode given their thickness. During excavation, most materials occurred either flat on the excavated surface or with minor tilting, suggesting limited vertical migration of materials. This is further supported by the sterile 5 cm separating BK1 and BK2. When mapping the excavated level without differentiating depths of materials, artifacts and fossils are distributed across most of the excavated area, with no immediately discernible pattern. However, if we map the finds by 5 cm vertical spits, discrete depositional events become clearer (Fig. 3). This cautions against seeing apparent patterns in spatial associations, which, in fact, result from lumping artifacts and fossils from dispersed vertical locations, as is common in several of Leakey's (1971) distribution maps from some Olduvai sites.

The vertical depth of the archaeological deposit at BK (about 3 m) shows that hominins re-occupied this place several times. Ostrich eggshells are abundant across all four archaeological levels, as initially reported by Leakey (1971). It could be argued that no natural process would repeatedly concentrate eggshell in the same spot over the vast period of time indicated by 3 m of sedimentation. Taphonomic studies of ostrich bones and their gastroliths have been undertaken (Wings, 2003) but we are not aware of any taphonomic study of a similar ostrich eggshell accumulation by natural processes. However, it has been documented that ostriches occasionally select the same places for nesting, and their communal nesting habits may produce accumulations of large amounts of eggshell on the same spot (Bertram, 1992). Therefore, the possibility of a natural origin for the accumulation of eggshell cannot be dismissed.

The geology of BK

We distinguished 13 geological levels in our trench, which are described from top to bottom as follows (Fig. 4):

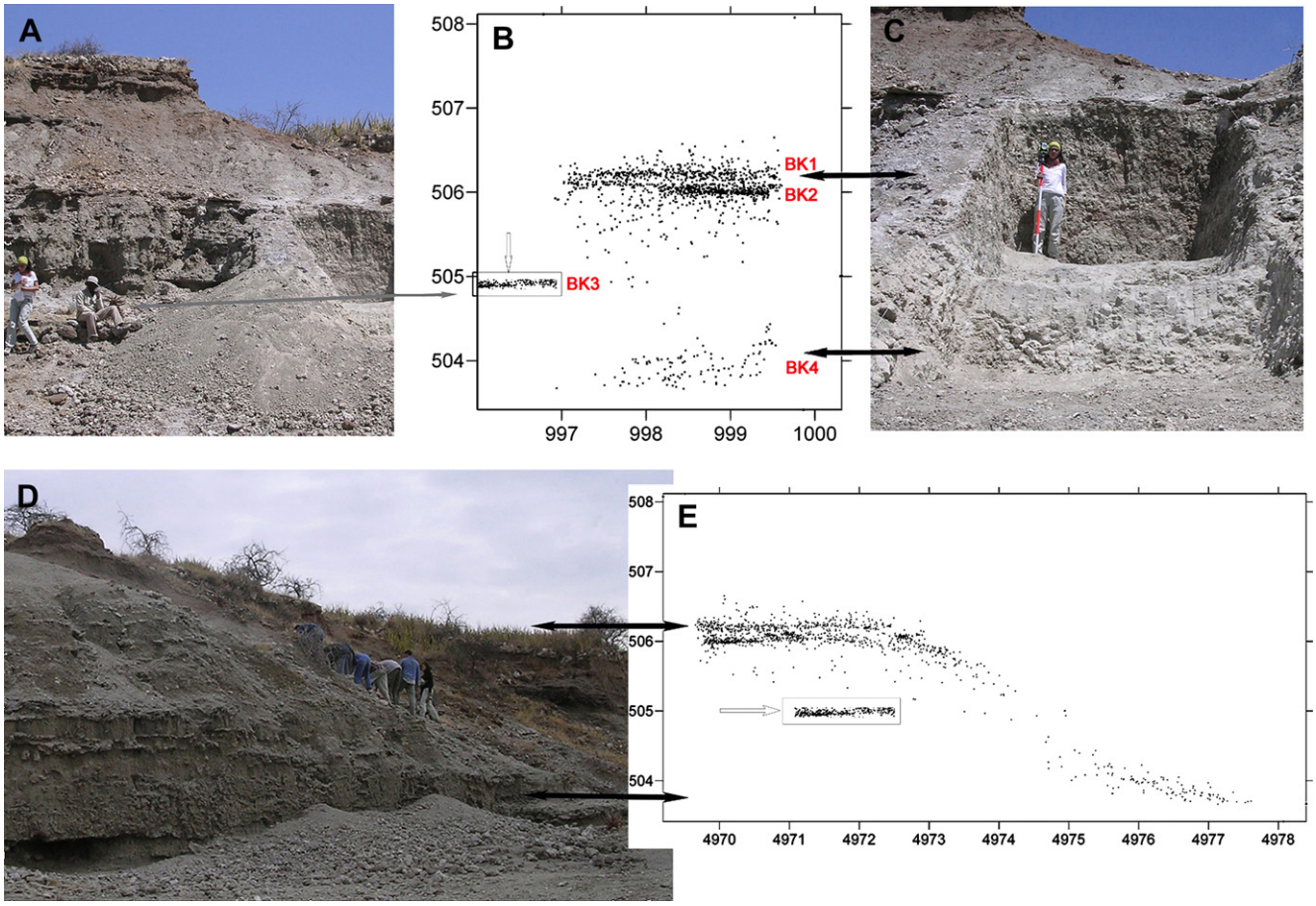

Figure 2. Spatial distribution of the archeological materials excavated at BK. A: Leakey's trench on the left (people are sitting at the exhibition level, i.e., BK3), and our trench on the right. B: Spatial distribution of artifacts and fossils as seen from the front of our trench showing the four levels: BK1 and BK2 are the two densest upper bands of points; the exhibit level (corresponding to BK3) is shown in a rectangle on the left to indicate the level at which it was found outside the trench (the arrow indicates its location in image A); BK4 is the vertically dispersed level at the bottom. C and D: The profiles of BK and the location of each level. BK3 is shown in a rectangle to indicate that its location is outside the trench. E: Lateral projection of the vertical distribution of artifacts and fossils.

BK-G1: White-yellow limestone with an irregular surface and nodular texture.

BK-G2: Gray-greenish clay with abundant carbonate nodules, randomly distributed. The first 30 cm of this level have fine-grained sand lenses.

BK-G3: Green fine-grained sand with abundant carbonate nodules at the base spanning a maximum of 20 cm.

BK-G4: Gray-greenish clay with carbonate nodules at the top. The contact with the underlying layer is marked in the east whereas it seems more gradual and transitional in the west, with increasing amounts of sand.

BK-G5: Medium- to fine-grained sand with clay lenses of variable proportions.

BK-G6: Sandy clay with rare carbonate nodules at the base.

BK-G7: Coarse-grained green sand. The contact with the overlying level is diffuse.

BK-G8: Gray-greenish clay, including strongly cemented patches at mid-level. The clay changes to dark brown at the base.

BK-G9: Yellow cemented sand. The top has randomly distributed coarse-grained sand lenses. This level shows a channel-like morphology. The base is composed of diagenetic limestone, representing carbonate precipitation in the base of the channel after sedimentation.

BK-G10: Gray-greenish clay.

BK-G11: Micro-conglomerate and coarse-grained sand. Gravel containing small rounded pebbles of limestone with smaller amounts of quartz and basalt. The matrix is a yellow sandy clay.

BK-G12: Light brown clay with numerous bioturbations ca. 1–2 mm in diameter of irregular shape and random distribution.

BK-G13: Clayey yellow sand.

The sedimentary environment that created this sequence was likely a distal alluvial system, given that most sediments are fine-grained. Even the micro-conglomerates are extremely small-sized and no large structures or channels were observed. The fluvial system would correspond to a section of a river near a lake. It shows oscillations (probably related to seasonality), as suggested by the diagenetic carbonate nodules. The presence of sandy clay indicates an environment of riverine margins, intermittently occupied by an ephemeral channel that frequently changed paths. BK 1 was found in the geological unit G6, a sandy clay. BK 2 is located within G7 (sand) and G8 (clay). BK 3 is located in G9 (sand) and BK 4 includes G10-13 (sands and silts). The sequence seems to correspond to a mudflat near the terminal edge of an alluvial fan. This created a low-relief environment in which the channel-fill sediments formed shallow strata and produced sheet-flood deposits. The carbonate levels indicate transgressive periods of the lake, which sometimes covered the site.

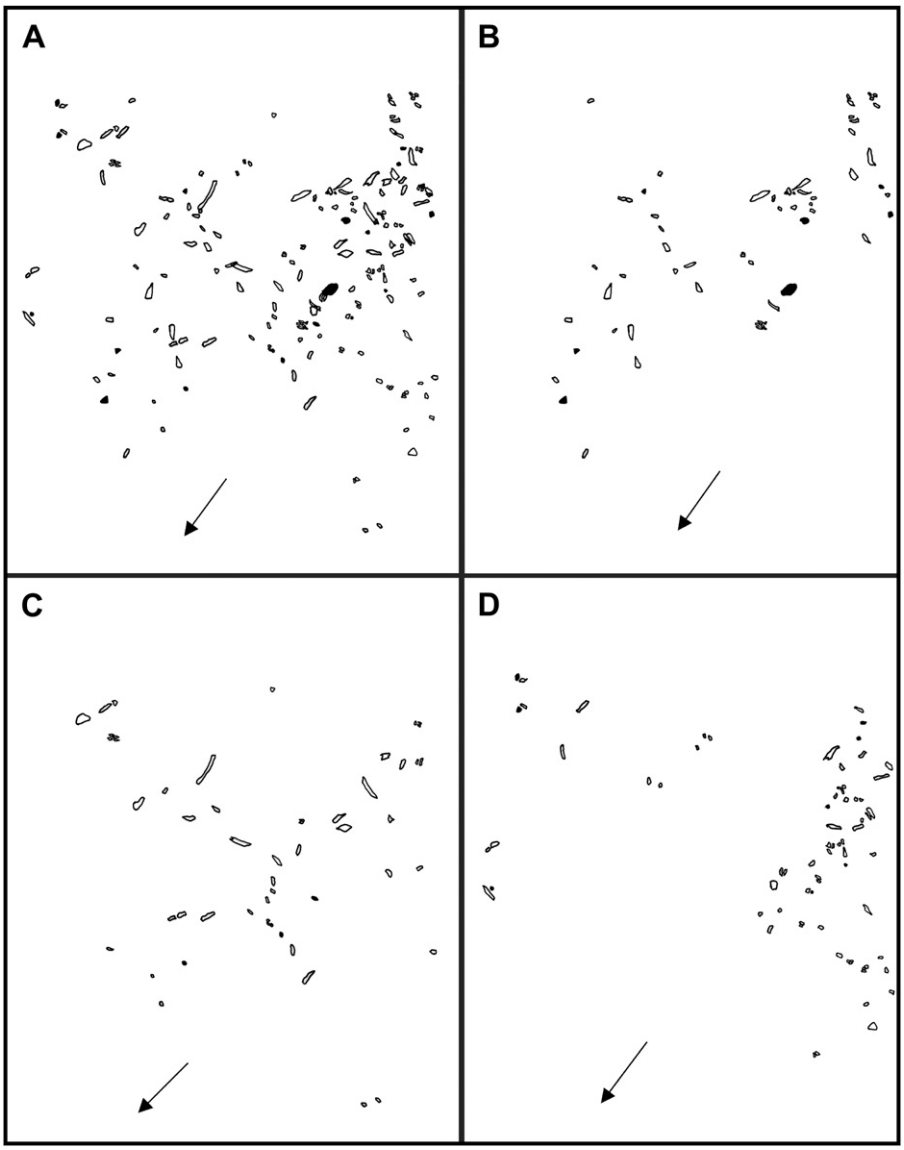

Figure 3. A: Spatial distribution of remains in the first 15 cm of level BK1. When splitting the distribution of stone artifacts (black) and fossils (white) by 5 cm spits, the spatial distributions show patterns more accurately reflecting independent depositional moments. B: Top 5 cm of BK1, C: BK1 at 10 cm, D: BK1 at 15 cm. Arrow indicates North.

Taphonomic study of the faunal remains: method and sample

Methods

Our methods were designed to assess site integrity, site formation processes, and the relative contribution of different biogenic agents to the formation of the faunal and lithic assemblages. First, we looked at site integrity and formation processes. Size-sorted assemblages created by water jumbles tend to be biased towards larger fragments; therefore, we measured the maximum length of fragments and used the distribution of specimen sizes to detect any possible preservation bias. We also looked for signs of polishing or abrasion, which would be expected in transported assemblages. Determining whether or not the assemblage is in primary *versus* secondary position is particularly important given the fluvial depositional context of the site.

Appendicular and axial elements, including all limb shaft fragments, were identified to element whenever possible. In our consideration of skeletal part representation, carcasses were divided into anatomical regions: skull (horn, cranium, mandible, and teeth), axial (vertebrae, ribs, pelvis, and scapula)[1] and appendicular (limb bones). Long limb bones were further divided into upper (humerus and femur), intermediate (radius and tibia), and lower (metapodials) limb bones (Domínguez-Rodrigo, 1997a). Skeletal part profiles were based on NISP (Number of Identified Specimens) and estimates of the MNE (Minimum Number of Elements). We also considered profiles by carcass size. "Small" refers to Bunn's (1982) sizes 1 and 2, and "large" refers to sizes 3, 4, and 5. We lumped Bunn's middle-sized and large carcasses (i.e., those >size 3) for BK1, BK2, and BK4 since size 4 and size 5 carcasses make up a very small fraction of the assemblage: most of the bones reported for the "large" category in BK1, BK2 (>90%), and

[1] We are aware that pelves and scapulae have traditionally been classified separately, but given their overall similarity in bone texture and taphonomic properties, we decided to lump them together with vertebrae and ribs, since all these elements are mostly cancellous and fragile. This has proven especially useful in the classification of specimens from the most fragmented assemblages (see Domínguez-Rodrigo et al., 2007).

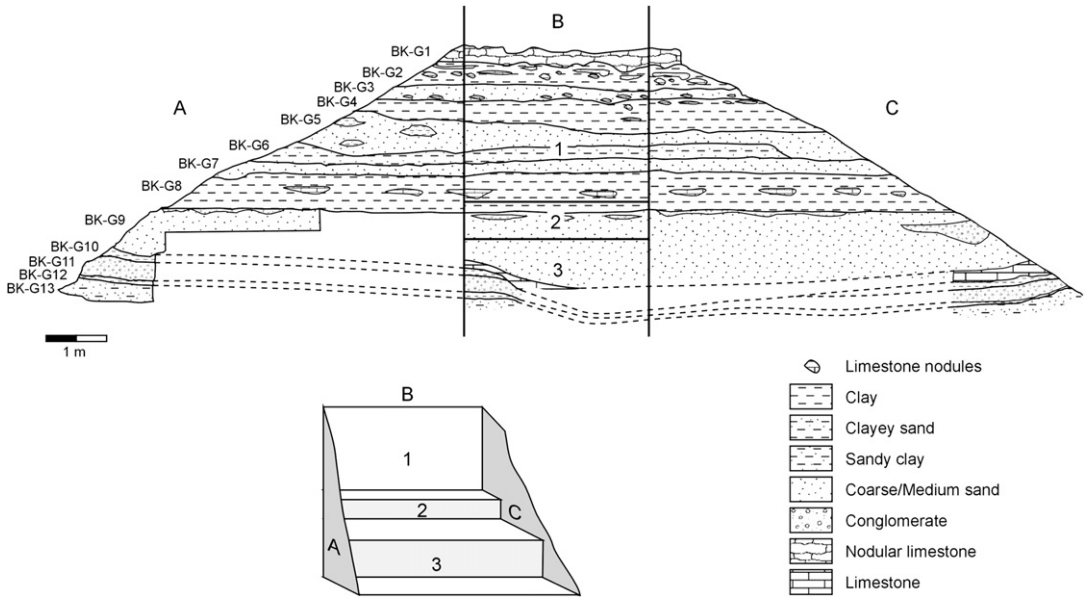

Figure 4. Geological distribution of sediments in the excavated trench.

BK4 belong to Bunn's size 3. We made an exception for BK3 (exhibit level) where the remains of larger fauna, especially size 4, make up one-third of the assemblage. Juveniles of size 3 animals (of which there were very few), whose weight estimates were <100 kg, were also classified as small since they would have shared the taphonomic properties of similarly sized animals.

Estimates of MNE at the Olduvai sites often differ substantially depending on whether epiphyses or shafts are used for element identification (Domínguez-Rodrigo et al., 2007). This discrepancy indicates intervening taphonomic processes, probably related to carnivore ravaging, biasing the original number of elements. In the present analysis, given the paucity of epiphyseal ends ($n = 11$), MNE estimation for long limb bones was based on the use of shafts (Pickering et al., 2003). To calculate MNEs, some researchers use a GIS-based method (Marean et al., 2001). We feel more confident in the estimation of elements if overlap among specimens is documented by hand. Therefore, we employed an integrative approach using the bone section division proposed by Patou-Mathis (1984, 1985), Münzel (1988), and Delpeche and Villa (1993), as described in detail in Yravedra and Domínguez-Rodrigo (2009). Following Delpeche and Villa (1993) and Münzel (1988), shafts were divided by equally-sized sectors, irrespective of areas of muscular insertion. These sectors (upper shaft, mid-shaft, lower shaft) can be easily differentiated and oriented (cranial, caudal, lateral, medial). Yravedra and Domínguez-Rodrigo (2009) described the criteria used in the division of each shaft sector, taking into account the orientation of each specimen. We also considered the criteria used by Barba and Domínguez-Rodrigo (2005) for long limb element identification, which is based on shaft thickness, section shape, and properties of the medullary surface. After identifying specimens to element and shaft sector using these methods, MNE was quantified by laying out all specimens from the same element and size group together. In this way, the criteria used in a comprehensive analysis (Lyman, 1994) such as element size, side, age, and biometrics, could be observed by comparing specimens side by side.

Recently, Faith and Gordon (2007) have demonstrated that skeletal element abundances can be quantified using Shannon's evenness index. Citing optimal foraging theory, they noted that the degree to which foragers select carcasses for transport will be reflected in the evenness of the distribution of specimens across classes of high-survival elements (*sensu* Marean and Cleghorn, 2003; Cleghorn and Marean, 2004). The axial postcranial skeleton is characterized by low survival, due to its overall low density and resulting preservation biases. In contrast, crania and appendicular elements are higher-density anatomical regions that better survive taphonomic processes and, if properly identified and quantified, can shed light on the carcass butchery and transport decisions made by foragers (Marean, 1998; Marean and Cleghorn, 2003). In situations where entire carcasses are transported, or where no transport has occurred, there should be a perfectly even distribution of these high-survival skeletal elements (standardized by their frequency in the vertebrate body). As transport becomes increasingly selective, the evenness of the distribution of these skeletal elements will decline. The interpretation that stems from this method is that an even representation of cranial and long limb bones would indicate short-distance transportation of carcasses, whereas an uneven index would suggest long-distance transportation.[2] We applied this method, standardizing our limb MNE estimates by first transforming them into MAU, then calculating Shannon's evenness index (Faith and Gordon, 2007; Faith et al., 2009).

Given the importance of determining the intervention (and possible interaction) of hominins and carnivores in the faunal assemblage, the study of bone surface modifications is an essential part of our analysis. We evaluated cortical surfaces and analyzed bone surface modifications, such as cut marks, tooth marks, percussion marks, and natural marks (biochemical and abrasion marks). Marks were identified using hand lenses under strong direct light, following the methodological and mark-diagnostic criteria specified by Blumenschine (1988, 1995) and Blumenschine and Selvaggio (1988, 1991) for tooth and percussion marks, and by Bunn (1981) and Domínguez-Rodrigo (1997a, 2002) for cut marks. To compare archaeological data to modern experimental referential frameworks where there is no diagenetic bone breakage or differential bone surface preservation, frequencies of marks are shown as

[2] This method still requires some refinement since there are many uncontrolled variables in play, such as the number of adults transporting carcasses, the carcass size, the time of day, immediate hunger level, and group food preferences.

both raw estimates and corrected estimates. Corrected estimates were obtained following Pickering et al. (2008): their method considers the artificial inflation of specimens through dry breakage and the artificial reduction of mark frequencies when specimens with poor cortical preservation are compared with specimens with good cortex. Pickering et al. (2008) recalculated the original number of bone specimens prior to dry breakage by subtracting the number of specimens with dry breakage divided by two, and then subtracting the number of specimens with poor cortical preservation. The reliability of this method is logical, since it excludes the specimens with poor preservation, which would bias the preserved frequencies of marks, and compensates for the duplication of specimens resulting from the dry breaking of single specimens, which would artificially inflate the original bone sample.

Tooth marks and percussion marks were analyzed using epiphyseal and mid-shaft long limb bone portions, following Blumenschine's (1988) method; however, we did not use the near-epiphyseal portion because of disagreements with the way this portion is defined and how marks are tallied (Domínguez-Rodrigo and Barba, 2006). For example, a 10 cm shaft specimen that preserves 1 cm of spongeous/trabecular tissue on its medullary surface could be classified as a near-epiphyseal portion even if marks clearly occur on the mid-shaft part, which is 90% of the specimen. Given that the identification of epiphyseal specimens (following Blumenschine's nomenclature) is straightforward, we tallied marks on epiphyseal fragments because they could be analogically interpreted with available experiments. However, given that the proportions of near-epiphyseal fragments identified by Blumenschine's (1988) analogical sample and our fossil sample would certainly differ, we decided to exclude this category because we could not guarantee that it would correspond to the experimental sample and, therefore, be adequately interpreted.

Cut marks were tallied by element type and bone section, following Domínguez-Rodrigo (1997a). Domínguez-Rodrigo et al. (2007) showed that a useful approach for differentiating primary *versus* secondary access to carcasses by hominins involves focusing on the parts of the bones where no scrap of flesh survived in an experimental sample of felid-consumed carcasses. These parts were defined as "hot zones," and stand in contrast to "cold zones," i.e., parts of the bone where scraps might survive because of stronger muscle attachments. The latter include the medial shaft of the humerus and the caudal side of the femur, tibia, and radius-ulna (Domínguez-Rodrigo et al., 2007; Barba and Domínguez-Rodrigo, 2008). Documentation of the precise location of cut marks on each limb bone in experiments reproducing human butchery of fully-fleshed carcasses revealed that hot zones are cut-marked in broadly similar frequencies to cold zones but with differences by element (Domínguez-Rodrigo et al., 2007). For humeri, both zones are cut-marked similarly in small carcasses, while in medium-sized carcasses cold zones show higher cut-mark frequencies. This is partially accounted for by the *M. pronator teres* and *M. biceps brachialis* attachments. For small carcass femora, both zones again show similar cut-mark frequencies while hot zones are cut-marked more frequently in medium carcasses. The hot zones of both carcass sizes are also more frequently cut-marked in radii. Most of the cut marks observed on radii cluster in hot zone 2 (cranial aspect). Cut marks on tibiae are similarly represented in both zones. This study demonstrated that the zone approach provides a useful framework for interpreting cut marks in fossil assemblages: cut marks in experiments modeling primary access are found in hot zones at similar or slightly lower frequencies than in cold zones, whereas cut marks have not been found in hot zones after butchery of lion kills (Domínguez-Rodrigo et al., 2007). In the present study, cut marks were drawn on templates, when their precise location could be identified, enabling this approach.

During excavation, we had to overcome sediment compaction and its effects on bones. Several showed cracks and diagenetic breakage planes that caused bone fragmentation as specimens were removed from the soil. This was documented across the entire sequence but especially in the *Pelorovis* level (BK4). Therefore, dry breakages are present in the archaeofaunal assemblage. The identification of green and dry (including diagenetic) breakages was carried out following Villa and Mahieu's (1991) criteria: dry breaks result in abundant breakage planes that are longitudinal and transverse to the axis of the bone, the angle measured between the cortical and medullary surfaces is close to 90 degrees, and the breakage plane surface is uneven, with micro-step fractures and a rough uneven texture. In contrast, green-broken specimens frequently have smoother surfaces and more abundant oblique breakage planes. Several specimens were fractured during excavation upon exposure but were glued before removal and/or in laboratory treatment.

Breakage patterns were analyzed using three complementary techniques outlined by Domínguez-Rodrigo et al. (2007). First we studied notches, which are defined as semi-circular outlines along the otherwise rectilinear edge of a fracture surface, associated with a negative flake scar on the medullary surface. These were measured to differentiate between bone breakage processes: Capaldo and Blumenschine (1994) showed experimentally that the dynamic force of hammerstone percussion produces notches that are broader and shallower in cortical view than the notches created by the static loading of carnivore teeth. They measured notch shape using two ratios: 1) notch breadth: notch depth (in cortical view), and 2) flake scar breadth: notch depth.

The platform angles of bone flakes removed during percussion also tend to be more acute/obtuse than those of flakes removed during carnivore bone breakage. Using a goniometer, the platform angle was measured at the loading point on the negative scar of the detached flake. Notch measurement still has the disadvantage of lacking a proper interpretive referential framework. The sample sizes used by Capaldo and Blumenschine (1994), especially for middle-sized carcasses, are too small and yield ambiguous and overlapping ranges of variation when comparing static and dynamic bone breakage processes. The analysis of notch measurement was therefore used with caution in the present work.

The second approach involved the study of notch morphology frequencies. Capaldo and Blumenschine (1994) differentiated seven types of notches, including double-overlapping and double-opposing notches said to be more abundant in carnivore bone breakage (Domínguez-Rodrigo et al., 2007). In our preliminary experimental work, we observed that certain notch types varied in frequency depending on whether static or dynamic loading was applied. Double-overlapping and double-opposing notches on bones from small and middle-sized carcasses occurred in higher frequencies in assemblages of broken bovid fragments created through static loading (Domínguez-Rodrigo et al., 2007).

A third approach involved the study of oblique breakage planes longer than 4 cm. On these planes, we measured the angle they formed with respect to the cortical surface. The physical principle is the same as for notches: dynamic loading (i.e., hammerstone percussion) creates more acute or obtuse angles than static loading (i.e., carnivore gnawing), which creates more right angles (Pickering et al., 2005; Alcántara et al., 2006).

Results

Skeletal part representation

A total of 1041 bone specimens larger than 2 cm were excavated from our trench at BK1, BK2, and BK4. The exhibit level (BK3)

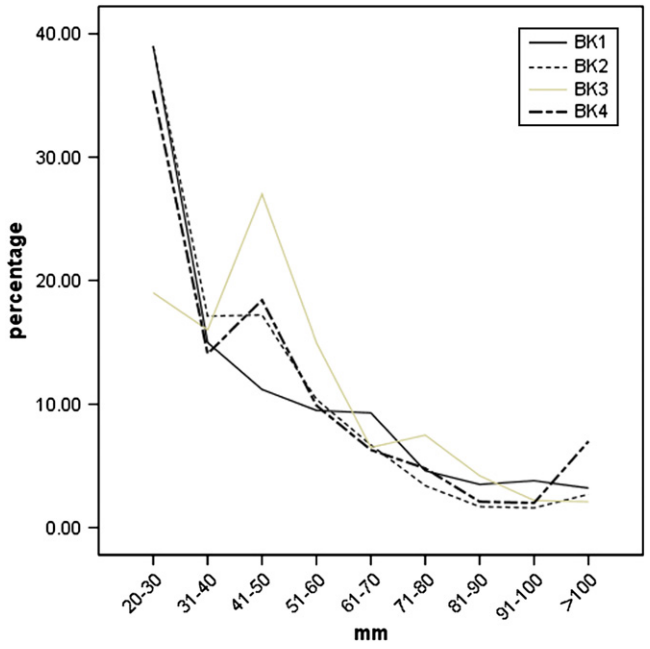

Figure 5. Distribution of bone specimen size ranges (maximum length in mm) in each level at BK.

produced an additional 396 specimens. Another 4,989 fragments <2 cm were also retrieved from our trench but are excluded from the present analysis. Looking at specimen size distribution in each assemblage, the smallest fragments (20–30 mm) are the most represented (Fig. 5). This is further supported by the hundreds of specimens <2 cm in BK1, BK2, and BK4 that are not included in Fig. 5. Specimens <4 cm are less represented in BK3 for unknown reasons. Given that this exhibit level was exposed for a long time, smaller fragments might have disappeared during the rains; alternatively, they could be underrepresented because this level was formed in a fluvial context and smaller fragments may have been washed away. Despite the overall minimal post-depositional disturbance by physical agents, water transport must have played some role in the final configuration of all these assemblages; although no predominant orientation was detected, some specimens were found to be tilting vertically[3] and 22 specimens (1% of NISP) showed traces of polishing and abrasion due to water transport. Overall, the assemblages appear to be well preserved and only minimally affected post-depositionally.

In terms of taxonomic distribution, BK1 is dominated by alcelaphini and antilopini (Table 1), including elements from most of the anatomical areas, with a high number of long limb bone shafts and rib fragments (Table 2). BK2 shows a similar taxonomic representation but with more equids (Table 1). The skeletal part profile includes specimens from most of the skeleton, but long limb shafts are more abundant and rib fragments less abundant than in BK1 (Table 3). BK3 contains more bones from large fauna >500 kg, but middle-sized animals are the best represented, with elements from the entire skeleton except for under-representation of vertebrae and ribs (Table 4). This level contains the highest number of epiphyseal fragments ($n = 7$) despite the small excavation area, in contrast to the larger areas of the other levels. BK4 also includes

[3] Vertical tilting could also result from natural movement of specimens lying on loose, sandy sediment.

Table 1
Minimum number of individuals identified at BK.

Level 1			
	Antilopini	1	Adult
	Gazella sp.	1	Adult
	Damaliscus cf. *niro*	1	Adult
	Connochaetes sp.	1	Subadult
	Kolpochoerus sp.	1	Adult
	Equus sp.	1	Subadult
	Mammalia size 4	1	Subadult
	Giraffidae	1	Adult
Level 2			
	Antilopini	2	1 adult, 1 subadult
	Alcelaphini size 3A*	1	Adult
	Connochaetes sp.	1	Adult
	Equus sp.	2	1 adult, 1 subadult
	Kolpochoerus sp.	1	Subadult
	Metriochoerus sp.	1	Adult
	Suidae indet	1	Subadult
	Mammalia size 4	1	Adult
Level 3			
	Antilopini	1	Adult
	Alcelaphini size 3A*	2	Adult
	Hippotragus sp.	2	1 juvenile, 1 adult
	Kobus sp.	1	Adult
	Mammalia size 4	1	Adult
	Pelorovis sp	1	Juvenile
	Equus sp.	2	1 juvenile, 1 adult
Level 4			
	Antidorcas	1	Adult
	Antilopini	1	Adult
	Alcelaphini size 3A	1	Adult
	Equus sp.	2	Juvenile
	Mammalia size 4	1	Subadult
	Diceros bicornis	1	Adult
	Crocodrilus sp.	1	Juvenile

* *Damaliscus*/*Parmularius*.

larger animals (Table 1), with an overall similar skeletal representation to the overlying levels (Table 5).

All the levels share a virtual lack of carpals, tarsals, phalanges, and vertebrae, and an under-representation of ribs (when considered as MNE instead of NISP), pelves, scapulae, and long limb epiphyses. The least dense parts of the skeleton seem to be underrepresented through the entire sequence. This is clear when looking at skeletal part profiles using MNE estimates (Table 6). Here, rib MNE estimates are substantially lower than NISP values because of the frequent fragmentation of these elements and also because element quantification is more difficult when using the most commonly represented rib shaft sections. However, we are confident that our low estimates of ribs are not merely a by-product of methodology, since we carefully compared all the specimens while considering the animal size, element width, and section, to minimize the impact of differential identification of ribs when compared to more easily quantifiable elements.

Skulls (crania and mandibles) and long limb bones are similarly represented, using expected MNE values according to MNI. This suggests non-selective behavior in the accumulation of remains. Most carcasses in all levels show a fairly even representation of the dense skeletal elements, including all long limb bone types (upper, intermediate, and lower). This is clear when Shannon's evenness index is calculated in each level (Fig. 6). This evenness of element representation may suggest low transport cost, probably related to complete limb transport to the site and/or short-distance transport of carcasses (Faith et al., 2009). The only minor exceptions are the small fauna in BK3, whose elements are more unevenly represented, probably due to a small sample size, and the high number of metapodials (e.g., among small animals in BK2 and larger animals in BK1) where these elements are better represented than upper limb bones.

Table 2
Number of identifiable specimens (NISP) according to carcass size discovered at BK level 1.

		Small	Large*	Indet. Size
Horn				
Skull		5	1	
Teeth			9	9
Mandible		2	2	
Cervical vertebrae				
Thoracic vertebrae		1		
Lumbar vertebrae				
Sacral vertebrae				
Vertebrae indet.		2	2	
Pelvis			2	2
Scapula				
Ribs		42	23	4
Humerus				
	Proximal end			
	Shaft	6	10	1
	Distal end		1	
Radius-ulna				
	Proximal end		1	
	Shaft	4	8	
	Distal end			
Metacarpal				
	Proximal end			
	Shaft	1	15	2
	Distal end			
Femur				
	Proximal end			
	Shaft	7	7	
	Distal end			
Tibia				
	Proximal end			
	Shaft	5	31	
	Distal end			
Metatarsal				
	Proximal end		2	
	Shaft	7	9	
	Distal end			
Carpals/Tarsals			1	
Phalanges				
Other				
ULB**		2	9	
ILB**			2	
ILLB**		1	10	
Indet.		12	38	49***
Total		97	183	347

* Only 18 specimens belonged to animals larger than size 3.
** ULB, upper limb bones; ILB, intermediate limb bones; ILLB, intermediate lower limb bones.
*** Includes 13 indeterminate shafts.

Table 3
Number of identifiable specimens (NISP) according to carcass size discovered at BK level 2.

		Small	Large*	Indet. Size
Horn		1	1	
Skull		11	13	
Teeth		2	20	
Mandible		3	9	
Cervical vertebrae				
Thoracic vertebrae				
Lumbar vertebrae				
Sacral vertebrae				
Vertebrae indet.		2	2	
Pelvis			3	
Scapula		1	2	
Ribs		23	22	
Humerus				
	Proximal end			
	Shaft	4	31	
	Distal end		1	
Radius-ulna				
	Proximal end		1	
	Shaft	4	15	
	Distal end			
Metacarpal				
	Proximal end		1	
	Shaft	4	25	
	Distal end		2	
Femur				
	Proximal end			
	Shaft	4	11	
	Distal end			
Tibia				
	Proximal end			
	Shaft	12	33	
	Distal end			
Metatarsal				
	Proximal end			
	Shaft	6	18	
	Distal end			
Carpals/Tarsals				
Phalanges				
Other				
ULB**		5	21	
ILB**		1	3	
ILLB**		12	37	
Indet.		20	99	101
Total		115	370	101***

* Only 21 specimens belonged to animals larger than size 3.
** ULB, upper limb bones; ILB, intermediate limb bones; ILLB, intermediate lower limb bones.
*** Includes 34 indeterminate shafts.

The skeletal pattern represented in all BK levels suggests either selective transport of skulls and complete limbs by collecting agent(s) with minor post-depositional carnivore ravaging (deleting limb ends and compact bones only), or transport of complete carcasses with intense carnivore ravaging (deleting axials, limb ends, and compact bones) (Marean and Spencer, 1991; Marean et al., 1992, 2004; Capaldo, 1995). The absence of vertebrae supports the former proposition better than the latter, but the presence of ribs could be used to support the latter interpretation; alternatively, one could find support for a mixed pattern involving complete transport of a few carcasses and selective transport of several others. The question of the vertebrae is problematic, since modern foragers (e.g., the Hadza) often transport them already defleshed and then boil them to render fat, affecting their representation in ethnographic assemblages (Bunn, 2007). Fat exploitation is not considered likely in Plio-Pleistocene contexts, so the use of Hadza as an analogue for the transport of axial elements by early hominins may not be appropriate. If hominins had transported vertebrae, it would imply that their transport must have been carried out on fleshed sections instead of defleshed ones, as documented among the Hadza. Carnivore ravaging could be seen as minimal, given the paucity of tooth-marked specimens (below), but the presence of so many long limb shafts and the virtual absence of epiphyses suggest a much more intense deletion of bone sections by carnivores.

Bone breakage

Most of the bone specimens show clear signs of green breakage. Dry breakage is a more variable but significant part of the assemblage, ranging between 12% and 24.5% of bone fractures, depending on the level (Table 7). On average, almost one out of every five specimens shows at least one dry breakage plane. However, the predominance of green breaks suggests dynamic- or static-loading breaking processes resulting from a biotic agent (human or carnivore). When measuring most oblique planes >4 cm, breakage plane angles seem to be either too acute or too obtuse to be the result of static loading (Fig. 7). They are more similar to the angles resulting from dynamic hammerstone loading. This is further supported by the fact that tooth-mark

Table 4
Number of identifiable specimens (NISP) according to carcass size discovered at BK level 3.

		Small	Middle	Large	Indet
Horn					
Skull			3	3	
Teeth			16		
Mandible		1	10	6	
Cervical vertebrae					
Thoracic vertebrae			2	1	
Lumbar vertebrae				1	
Sacral vertebrae					
Vertebrae indet.			10	5	
Pelvis		1	3		
Scapula			4		
Ribs		22	10	2	
Humerus					
	Proximal end			1	
	Shaft	3	12	15	
	Distal end		1	1	
Radius-ulna					
	Proximal end		1		
	Shaft	1	8	4	
	Distal end				
Metacarpal					
	Proximal end			1	
	Shaft	4	9	2	
	Distal end				
Femur					
	Proximal end				
	Shaft		9	5	
	Distal end				
Tibia					
	Proximal end				
	Shaft	3	11	6	
	Distal end				
Metatarsal					
	Proximal end		2		
	Shaft	7	10	1	
	Distal end				
Carpals/Tarsals			4		
Phalanges		2	2		
Other					
ULB**		5	14	6	
ILB**		1	3	4	
ILLB**		3	21	5	
Indet.		4	40 (30 shafts)	62 (20 shafts)	6 (3 shafts)
Total		57	205	131	6

** ULB, upper limb bones; ILB, intermediate limb bones; ILLB, intermediate lower limb bones.

Table 5
Number of identifiable specimens (NISP) according to carcass size discovered at BK level 4.

		Small	Large*	Indet. Size
Horn		1	5	
Skull				
Teeth			9	1
Mandible		1	3	1
Cervical vertebrae				
Thoracic vertebrae				
Lumbar vertebrae				
Sacral vertebrae				
Vertebrae indet.			3	
Pelvis			1	
Scapula			1	
Ribs		2	5	
Humerus				
	Proximal end		1	
	Shaft	1	2	
	Distal end		1	
Radius-ulna				
	Proximal end			
	Shaft	1		
	Distal end			
Metacarpal				
	Proximal end			
	Shaft		1	
	Distal end			
Femur				
	Proximal end			
	Shaft		1	
	Distal end			
Tibia				
	Proximal end			
	Shaft	1	6	
	Distal end			
Metatarsal				
	Proximal end			
	Shaft		1	
	Distal end			
Carpals/Tarsals			5	
Phalanges			1	
Other			1	
ULB**			1	
ILB**			1	
ILLB**			6	
Indet.		3 (1 shaft)	32 (11 shafts)	12 (1 shaft)
Total		10	84	14

* Only 34 specimens belonged to animals larger than size 3.
** ULB, upper limb bones; ILB, intermediate limb bones; ILLB, intermediate lower limb bones.

frequencies are too low (below) to support the interpretation that bone-crunching carnivores such as hyenas broke most of the bones. Frequencies of percussion marks, on the other hand, are on the high end of the range for hammerstone-broken experimental assemblages (below), clearly suggesting that the bones were broken by hominins.

The study of notches also supports this interpretation. A total of 50 classifiable notches were documented (Table 8). Most of these were single notches, with a low frequency of double-overlapping and double-opposing notches similar to that seen in hammerstone-broken assemblages (Domínguez-Rodrigo et al., 2007). This is substantially different from carnivore-broken assemblages where such notches are more abundant. Notch measurement also shows large and shallow shapes, probably resulting from dynamic loading rather than static loading. However, as noted earlier, the referential framework for these data provides poor resolution, given the large overlap in the ranges of variation for dynamic and static loading for size 3 carcasses (Capaldo and Blumenschine, 1994). Therefore, notch measurement is not very useful here to discriminate the bone-breaking agent (Fig. 8).

Shaft circumference types, classified following Bunn (1982), are also an important analytical tool for understanding bone breakage patterns. In all levels at BK, Type 1 (<50% of the shaft circumference) is overwhelmingly predominant (Fig. 9). The difference with experimental assemblages lies in the lower frequency of Type 2 (>50% of the circumference) and especially Type 3 (complete circumference) at BK; this is probably related to the paucity of long limb epiphyses. Most BK levels resemble those experiments in which carnivores, either primarily or secondarily, have ravaged limb bones by removing epiphyses.

Bone surface modifications

Our analysis of percussion marks and tooth marks also suggests a lack of carnivore bone breakage at BK, and points to the role of hominins in extracting marrow from the limb bones of the carcasses accumulated in all archaeological levels. The available evidence suggests that carnivore activities seem to have been limited to grease extraction from the grease-bearing bone portions

Table 6
Estimates of Minimum Number of Elements (MNEs) for each skeletal part according to each level.

	Level 1		Level 2		Level 3			Level 4	
	Small	Large	Small	Large	Small	Mid-sized	Large	Small	Large
Horn			1	1				1	1
Skull	1	3	1	3		1	1		
Mandible	2	2	3	3	1	2	1	1	2
Cervical vertebrae									
Thoracic vertebrae						2	1		
Lumbar vertebrae							1		
Sacral vertebrae									
Vertebrae indet.	1	1	1	1		4	3		3
Pelvis		2		2	1	2			1
Scapula			1	1		2			1
Ribs	8	6	7	8	9	7	1	1	2
Humerus	4	4	2	7	1	5	4	1	2
Radius	1	2	1	5	1	3	0	1	
Ulna	1	2		4		2	2		
Metacarpal	1	9	3	7	4	6	1		1
Femur	4	5	1	5		5	2		1
Tibia	2	10	5	6	2	6	3	1	2
Metatarsal	2	6	4	6	4	5	1		1
Carpals/ Tarsals		1				5			5
Phalanges						4			1

abandoned by hominins. A bone surface is defined as well preserved when the whole original bone surface is preserved and unaffected by deterioration. Otherwise, it is defined as poorly preserved. Bone preservation is usually well preserved in the upper levels, with a variable but low proportion of carbonated or biochemically weathered specimens whose surfaces were invisible or poorly preserved and could not be studied (Fig. 10). In contrast to FLK Zinj (Domínguez-Rodrigo and Barba, 2006), biochemical marks affect a very small part of the assemblage, with most bone surfaces showing pristine preservation. BK3 is the least affected by poor bone surface preservation (17% of shaft NISP having poor cortical preservation), and BK4 is the most affected, with twice as many specimens (40% of the shaft assemblage) showing poorly preserved surfaces. As noted earlier, very few specimens bear traces of polishing and abrasion, despite being found in a fluvial context. This indicates that most bone surface modifications should have been visible and identifiable.

Here we present the distribution of each type of modification on the most widely represented long limb mid-shaft specimens (Table 9), and on each skeletal element (Tables 10–13) according to archaeological level. Tooth marks make up a very small fraction of bone surface modifications, occurring in low numbers in all levels. They are sparse on most elements, and on limb shafts the highest frequency (8.8% in BK2) is only obtained when correcting for bone surface preservation and dry-broken specimens. In all levels the frequency of tooth-marked shafts is <9%, which is similar to the percentage documented in experiments where hyenas have secondary access to

Table 7
Frequencies for green and dry breakage per level. Numbers in numerators are number of specimens with specific breakage type and numbers in denominators are for total number of specimens where breakage type was identified. Numbers in parentheses are for percentages.

	Level 1	Level 2	Level 3	Level 4
Green breakage	288/305 (94.4)	568/598 (94.9)	369/373 (98.9)	101/111 (90)
Dry breakage	75/305 (24.5)	87/598 (14.5)	46/373 (12.3)	21/111 (18.9)
Green and dry breakage	50/305 (16.3)	57/598 (9.5)	44/373 (11.7)	11/111 (9.9)

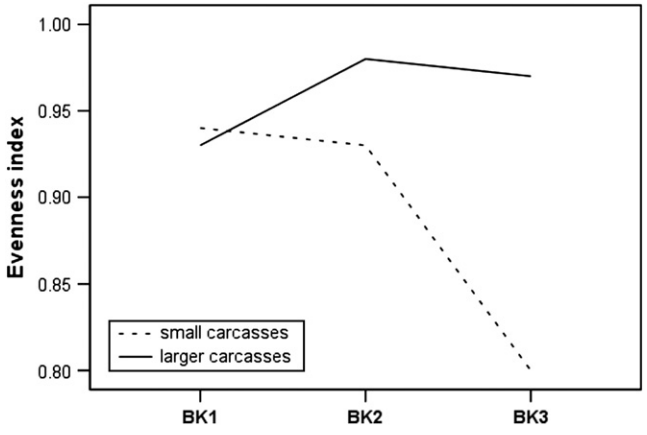

Figure 6. Shannon's evenness index in BK1-3 by carcass size. In BK4, sample size was too small to give a reliable result.

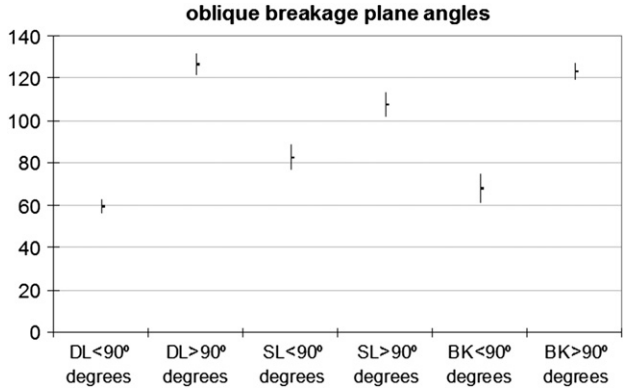

Figure 7. Mean and 1 S.D. values in mm for breakage plane angles (in degrees) for experimental assemblages on oblique planes modeling dynamic loading (DL; hammerstone percussion, perc.) and static loading (SL; carnivore tooth pressure, pres.) for large carcasses (Bunn's size 3), and for the BK assemblage (BK). Sample size for small carcasses was too small to produce meaningful results.

Table 8
Notch types in all archaeological levels at BK.

% single notches/all notches	41/50 (87)
% overlapping notches/all notches	6/50 (12)
% double-opposing notches/all notches	3/50 (6)

human-discarded bones (Domínguez-Rodrigo et al., 2007). In the BK3 shaft assemblage, tooth marks make up a marginal proportion of the modifications (<2.5% when corrected for bone surface preservation and dry-broken specimens).

Percussion marks are very abundant in all levels except BK4. When considering all shaft specimens, irrespective of dry breakage and surface preservation, frequencies at BK1, BK2, and BK3 range between 16% (BK2) and 20% (BK1) (Table 9). When correcting for these factors, and including all levels, the percentage of percussion-marked shafts is very high, ranging from 11% (BK4) to 32% (BK1) of all shaft specimens. This is clearly indicative of hominins breaking the long limb bones at the site (Figs. 11 and 12). It is noteworthy that when correcting for dry breakage and surface preservation, the percentage of percussion marks in small carcasses from BK3 seem to fit better with hammerstone-only experimental scenarios, in the absence of carnivore post-depositional ravaging; curiously, BK3 also shows the lowest frequency of tooth-marked specimens. This can also be observed in the frequencies of percussion-marked specimens from larger carcasses in BK1, BK2, and BK3. This relationship between a high frequency of percussion-marked limb bone shaft fragments and a low frequency of tooth-marked fragments is probably not accidental and is further support for a low degree of carnivore ravaging in the BK assemblages. Additional support comes from the study of "impact" flakes recovered at the site. Each level yielded an important number of impact flakes resulting from dynamic loading (Fig. 13), some of which bear percussion marks on their platforms (Fig. 14).

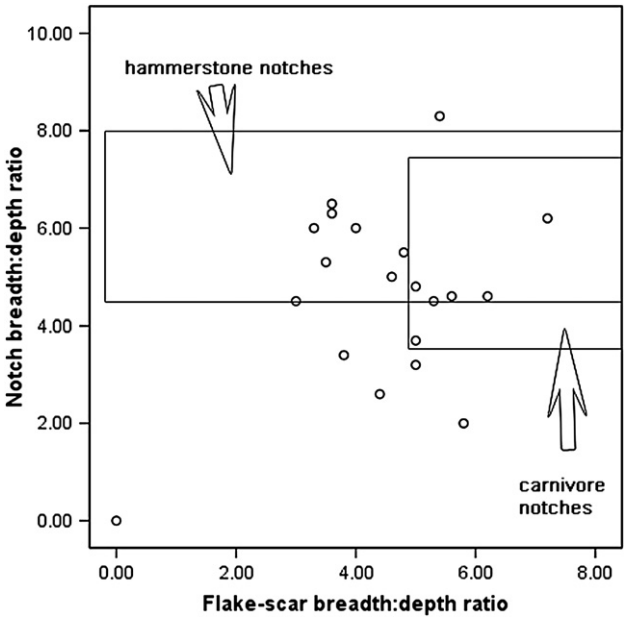

Figure 8. Ratios obtained from measurements of complete notches from non-metapodial long limb elements from size 3 carcasses at BK: notch length: breadth (as seen from the cortical surface) and flake scar length: breadth (as seen from the medullary surface). Boxes represent the 95% confidence intervals for ratios documented in experimental assemblages produced by static (carnivore) and dynamic (hammerstone percussion) loading (Capaldo and Blumenschine, 1994).

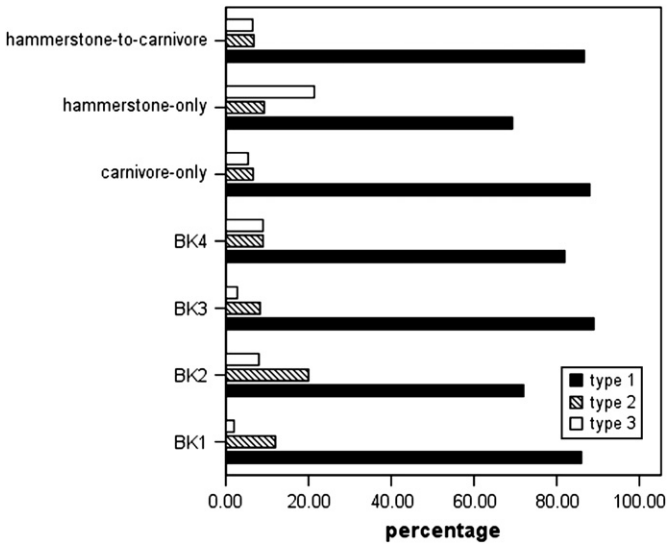

Figure 9. Distribution (%NISP) of Bunn's (1982) long bone shaft circumference types in the four levels at BK, and in experimental assemblages replicating hammerstone percussion, carnivore breakage, or a hammerstone-to-carnivore sequence (Marean and Spencer, 1991; Marean et al., 2004).

One of the most striking features of the BK bone assemblages is the high frequency of cut marks (Fig. 15). This frequency was derived very conservatively, given the presence of trampling on a portion of the bones. Some marks that could have potentially been cut marks (but did not show all the diagnostic features that identified them as such) were not counted when associated with clear signs of sediment abrasion. A total of 208 (19.9%) out of the 1045 bone specimens retrieved at BK bore traces of trampling or micro- and macro-abrasion resulting from the friction of bone against sandy sediment. In BK1, 15% ($n = 54$) of specimens bore traces of trampling or sediment abrasion; in BK2, this frequency is 20% ($n = 122$); in BK3, 16% ($n = 64$); and in BK4, 25% ($n = 28$). For this reason, specimens bearing marks similar to cut marks and having conspicuous traces of sediment abrasion prevented us from

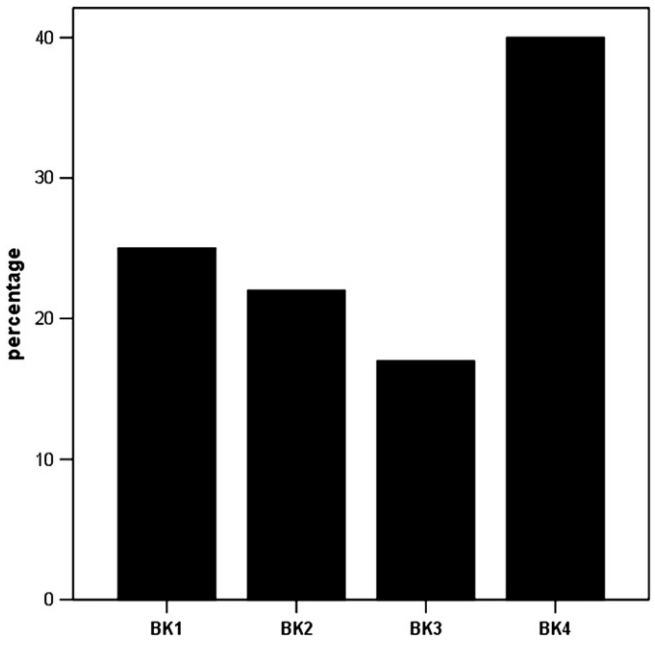

Figure 10. Percentage of shaft specimens with poor surface preservation in each BK level.

Table 9
Bone surface modifications according to carcass size for all bone specimens, including modifications found only on well-preserved surfaces and frequencies derived from excluding dry-broken specimens.

	Small			Large			Indet.			Total		
	TM	CM	PM	TM	CM	PM	TM	CM	PM	TM	CM	PM
Total marked mid-shafts (all specimens)												
BK1	2/36 (5.5)	3/36 (8.3)	6/36 (16.6)	7/119 (5.9)	14/119 (11.7)	27/119 (22.6)	0/13 (0)	3/13 (23)	2/13 (15.3)	9/168 (5.3)	20/168 (11.9)	35/168 (20.8)
BK2	4/66 (6)	3/66 (4.5)	8/66 (12.1)	14/245 (5.7)	37/245 (15.1)	41/245 (16.8)	0/34 (0)	2/34 (5.8)	3/34 (8.8)	18/310 (5.8)	42/310 (13.2)	52/310 (16.7)
BK4	0/4 (0)	0/4 (0)	0/4 (0)	1/30 (3.3)	2/30 (6.6)	2/30 (6.6)	0/1 (0)	0/1 (0)	0/1 (0)	1/35 (2.8)	2/35 (5.7)	2/35 (5.7)
Total marked mid-shafts (well-preserved specimens)												
BK1	2/30(6.6)	3/30 (10)	6/30 (20)	7/89 (7.8)	14/89 (15.6)	27/89 (30)	0/7 (0)	3/7 (42.8)	2/7 (28.5)	9/126 (7.1)	20/126 (15.8)	35/126(27.7)
BK2	4/55(7.2)	3/55 (5.4)	8/55 (14.5)	14/160 (8.8)	37/160 (23.1)	41/160 (25.7)	0/14 (0)	2/14 (14.2)	3/14 (21.4)	18/229 (7.8)	42/229 (17.9)	52/229(22.8)
BK4	0/4 (0)	0/4 (0)	0/4 (0)	1/16 (6.2)	2/16 (12.4)	2/16 (12.4)	0/1 (0)	0/1 (0)	0/1 (0)	1/21 (4.7)	2/21 (9.4)	2/21 (9.4)
Total marked mid-shafts (well preserved and corrected for dry-broken specimens)												
BK1	2/24(8.3)	3/24 (12.5)	6/24 (25)	7/78 (8.9)	14/78 (17.9)	27/78 (34)	0/6 (0)	3/6 (50)	2/6 (33.3)	9/108 (8.3)	20/108 (18.5)	35/108(32.4)
BK2	4/50(8)	3/50 (6)	8/50 (16)	14/140 (10)	37/140 (26.4)	41/140 (29.2)	0/14 (0)	2/14 (14.2)	3/14 (21.4)	18/204 (8.8)	42/204 (20.5)	52/204(25.4)
BK4	0/3 (0)	0/3 (0)	0/3 (0)	1/14 (7.1)	2/14 (14.2)	2/14 (14.2)	0/1 0)	0/1 (0)	0/1 (0)	1/18 (5.5)	2/18 (11)	2/18 (11)
Total marked mid-shafts (all specimens)												
		Small			Middle			Large			TOTAL	
BK3	1/27(3.7)	3/27 (11.1)	8/27 (29.6)	2/127 (1.5)	11/127 (8.6)	19/127(14.9)	0/68 (0)	9/68 (13.2)	8/68 (11.7)	3/222 (1.3)	23/222 (10.3)	35/222(15.7)
Total marked mid-shafts (well-preserved specimens)												
		Small			Middle			Large			TOTAL	
BK3	1/23(4.3)	3/23 (13)	8/23 (34.7)	2/97 (2)	11/97 (11.3)	19/97 (19.5)	0/57(0)	9/57 (15.7)	8/57 (14)	3/177(1.7)	23/177 (12.9)	35/177(19.7)
Total marked mid-shafts (well preserved and corrected for dry-broken specimens)												
		Small			Middle			Large			TOTAL	
BK3	1/20(5)	3/20 (15)	8/20 (40)	2/64 (3.1)	11/64 (17.1)	19/64 (29.6)	0/44(0)	9/44 (20.4)	8/24 (33.3)	3/128(2.3)	23/128 (17.9)	35/128(27.3)

identifying some probable cut marks; therefore, our estimates certainly under-estimate the original number of cut marks in the BK assemblages. Despite this, a total of 109 cut-marked specimens have been found at BK: 24 at BK1, 52 at BK2, 31 at BK3, and 2 at BK4. Almost all the cut marks documented on limb bones occur on shafts.

When plotting cut-mark distribution (corrected for bone surface preservation and dry-broken specimens) and comparing it with experiments modeling primary and secondary access to carcasses by hominins (Fig. 16a), it becomes evident that the BK data are more similar to those from experiments reproducing primary access to fleshed carcasses than those reproducing secondary access to defleshed carcasses. The data seem to be ambiguous in some elements because of experimental shortcomings (overlap in the ranges obtained for intermediate and lower limb bones) and also because of problems in comparability: the experiments were carried out on freshly-broken bone where no adjustment was performed to correct for diagenetic breakage, and the frequency of epiphyseal fragments in experimental assemblages was significantly higher than at any level in BK. For this reason, the frequencies of cut-marked specimens obtained for mid-shafts and epiphyses fall outside the ranges of variation documented experimentally. However, one of the variables used (ratio of cut-marked meaty-bone mid-shafts: cut-marked metapodial mid-shafts) was shown by Domínguez-Rodrigo (1999) to be very effective in differentiating primary from secondary access to carcasses. The frequencies of cut-marked meaty-bone mid-shafts at BK are too high to be the result of exploiting defleshed carcasses from felid kills. They suggest that hominins had primary access to carcasses. This is more clearly shown when the cut-mark data are treated with multivariate statistics (Fig. 16b).

Primary access can also be inferred from the distribution of cut-mark frequencies on long limb bones from the best-represented carcass size in each level at BK. Figure 17 shows the raw (uncorrected) percentages of cut-marked limb specimens from large carcasses: sizes 3 and 4 for BK1 and BK2, and size 3 only for BK3. In each level, the most cut-marked element is almost always an upper limb bone. Intermediate bones are almost as highly cut-marked as upper limb bones. When frequencies are corrected for dry breakage and surface preservation, upper limb bone shafts appear more highly cut-marked than either intermediate or lower limb bones at BK2 and BK3. This clearly points to primary access to large carcasses by hominins, according to comparisons with experimental data (Domínguez-Rodrigo, 1997a,b, 1999; Pickering et al., 2004a).

When documenting the precise location of cut marks in each section of meaty limb bones (Figs. 18 and 19), we observe the following features by element:

1. Humerus. Cut marks cluster on the distal shaft. Cut marks on the mid-shaft are more frequent on the medial side, in clear connection with the insertion of the *Teres*. The distribution of cut marks in cold zones and hot zones is similar to that documented experimentally when butchering completely fleshed carcasses, suggesting that carnivores never preceded hominins in defleshing humeri. Two distal epiphyseal specimens bear marks on the distal medial epicondyle and on its caudal aspect. This is suggestive of disarticulation, although marks in the caudal aspect have also been documented to be the result of filleting (Nilssen, 2000; Bunn, 2001). Cut marks on the medial side of the caudal epicondyle of these specimens can be attributable to disarticulation because cut marks also occur on the medial side of the trochlea (Nilssen, 2000) (Fig. 20). This is extremely relevant because these two specimens are among the oldest to show secondary disarticulation of the humerus-radius joint, which today is only documented at camps after the carcass limbs have been first disarticulated as whole units at the kill site (Bunn et al., 1988).
2. Femur. All marks documented are the result of defleshing, which is not surprising given the virtual lack of epiphyses at BK. Most cut marks occur in hot zones, i.e., parts of the bone where no scraps of flesh survive after initial consumption by carnivores. The distribution of cut marks in hot and cold zones is also very similar to that obtained experimentally when butchering fleshed carcasses (Domínguez-Rodrigo et al., 2007). The similarity in the distribution of cut marks on both humeri

Table 10
Frequencies of bone surface modifications on each skeletal part from Level 1. Numbers in numerators are for the number of specimens bearing marks; numbers in denominators are the total number of specimens; numbers in parentheses are the percentage. TM, tooth marks; CM, cut marks; PM, percussion marks.

		Small			Large		
		TM	CM	PM	TM	CM	PM
Skull		0/5 (0)	1/5 (20)	0/5 (0)	0/1 (0)	0/1 (0)	0/1 (0)
Mandible		1/2 (50)	0/2 (0)	0/2 (0)	0/2 (0)	0/2 (0)	0/2 (0)
Cervical vertebrae							
Thoracic vertebrae		0/1 (0)	0/1 (0)	0/1 (0)			
Lumbar vertebrae							
Sacral vertebrae							
Vertebrae indet.		0/2 (0)	0/2 (0)	0/2 (0)	1/2 (50)	1/2 (50)	0/2 (0)
Pelvis					1/2 (50)	1/2 (50)	0/2 (0)
Scapula							
Ribs		3/42 (7.1)	1/42 (2.3)	0/42 (0)	1/23 (4.3)	3/23 (13)	0/23 (0)
Humerus							
	Proximal end						
	Shaft	1/6 (16.6)	0/6 (0)	0/6 (0)	0/10 (0)	3/10 (30)	2/10 (20)
	Distal end				0/1 (0)	0/1 (0)	0/1 (0)
Radius-ulna							
	Proximal end				0/1 (0)	0/1 (0)	0/1 (0)
	Shaft	1/4 (25)	1/4 (25)	1/4 (25)	1/8 (12.5)	2/8 (25)	4/8 (50)
	Distal end						
Metacarpal							
	Proximal end						
	Shaft	0/1 (0)	0/1 (0)	0/1 (0)	0/15 (0)	0/15 (0)	5/15 (33.3)
	Distal end						
Femur							
	Proximal end						
	Shaft	0/7 (0)	0/7 (0)	2/7 (28.5)	0/7 (0)	0/7 (0)	1/7 (14.2)
	Distal end						
Tibia							
	Proximal end						
	Shaft	0/5 (0)	1/5 (20)	2/5 (40)	2/31 (6.4)	4/31 (12.9)	6/31 (19.3)
	Distal end						
Metatarsal							
	Proximal end				0/2 (0)	0/2 (0)	
	Shaft	0/7 (0)	0/7 (0)	0/7 (0)	1/9 (11.1)	2/9 (22.2)	2/9 (22.2)
	Distal end						
Carpals/ Tarsals					0/1 (0)	0/1 (0)	0/1 (0)
Phalanges							
Other							
ULB**		0/2 (0)	0/2 (0)	0/2 (0)	0/9 (0)	1/9 (11.1)	0/9 (0)
ILB**					0/2 (0)	0/2 (0)	0/2 (0)
ILLB**		0/1 (0)	0/1 (0)	0/1 (0)	0/10 (0)	1/10 (10)	2/10 (20)
Indet.		1/12 (8.3)	1/12 (8.3)	1/12 (8.3)	3/38 (7.8)	2/38 (5.2)	5/38 (13.1)
Total		7/97 (7.2)	5/97 (5.1)	6/97 (6.1)	10/183 (5.4)	19/183 (10.3)	27/183 (14.7)

** ULB, upper limb bones; ILB, intermediate limb bones; ILLB, intermediate lower limb bones.

and femora between BK and the experimental assemblages clearly indicates complete defleshing of carcasses by hominins and, therefore, primary access to carcass resources.

3. Radius. This is the only element at BK that differs from experimental assemblages in the distribution of cut marks. Cut marks on ulna fragments are more abundant than on radii. Only defleshing marks have been recorded on the latter, and no disarticulation marks; however, this may reflect the underrepresentation of ends.
4. Tibia. Once again, the distribution of cut marks in hot and cold zones at BK is similar to that documented in the experimental assemblages replicating primary butchery of fleshed carcasses, suggesting that hominins had primary access to meat resources.

Cut marks abound on meaty limb elements (Fig. 15) and–given the bias created by the near-absence of ends–overwhelmingly show filleting activities on most carcasses. With the exception of the two distal humeri specimens, no other disarticulation marks have been found. The few carpal and tarsal bones–usually substantially cut-marked during carcass disarticulation (Nilssen, 2000)–show no cut marks. Cut marks on metapodials occur on shafts and are related to skinning and possibly removal of the periosteum.

Cut marks have also been found on both the ventral[4] and dorsal sides of rib fragments in BK1, BK2, and BK3, reflecting evisceration of carcasses by hominins and further supporting the interpretation of primary access to fleshed carcasses. The sample of modified bone from BK4 is too small to draw any meaningful conclusion. However, it is worth noting two cut-marked specimens (belonging to a metacarpal and a tibia) and one percussion-marked specimen (belonging to a metacarpal) from a size 4 animal, suggesting that hominins may have exploited some of the *Pelorovis* remains that are so abundant in that level. This receives further support from the significantly larger portion of cut-marked bone specimens from large, size 4 animals at BK3. Cut-marked specimens from size 4 carcasses come from various elements (Table 12), including the mandible, vertebra, rib, and shafts of meaty bones (humerus,

[4] One rib specimen from a middle-sized carcass at BK1, two rib specimens from small carcasses at BK2, and three specimens from a middle-sized carcass at BK3.

Table 11
Frequencies of bone surface modifications on each skeletal part from Level 2. Numbers in numerators are for the number of specimens bearing marks; numbers in denominators are the total number of specimens; numbers in parentheses are the percentage. TM, tooth marks; CM, cut marks; PM, percussion marks.

		Small			Large		
		TM	CM	PM	TM	CM	PM
Skull		0/11 (0)	1/11 (9)	0/11 (0)	0/13 (0)	3/13 (23)	
Mandible		0/3 (0)	0/3 (0)	0/3 (0)	2/9 (22.2)	2/9 (22.2)	1/9 (11.1)
Cervical vertebrae							
Thoracic vertebrae							
Lumbar vertebrae							
Sacral vertebrae							
Vertebrae indet.		0/2 (0)	0/2 (0)	0/2 (0)	0/2 (0)	0/2 (0)	0/2 (0)
Pelvis					0/3 (0)		
Scapula		0/1 (0)	0/1 (0)	0/1 (0)	0/2 (0)		
Ribs		3/23 (13)	5/23 (21.7)	0/23 (0)	0/22 (0)	1/22 (4.5)	0/22 (0)
Humerus							
	Proximal end						
	Shaft	1/4 (25)	0/4 (0)	0/4 (0)	3/31 (9.6)	5/31 (16)	5/31 (16)
	Distal end				0/1 (0)		
Radius-ulna							
	Proximal end				0/1 (0)		
	Shaft	0/4 (0)	0/4 (0)	0/4 (0)	0/15 (0)	3/15 (20)	2/15 (13.2)
	Distal end						
Metacarpal							
	Proximal end				0/1 (0)		
	Shaft	0/4 (0)	0/4 (0)	0/4 (0)	1/25 (4)	5/25 (20)	6/25 (24)
	Distal end				0/2 (0)		
Femur							
	Proximal end						
	Shaft	0/4 (0)	0/4 (0)	0/4 (0)	1/11 (9)	3/11 (27.2)	0/11 (0)
	Distal end						
Tibia							
	Proximal end						
	Shaft	1/12 (8.3)	1/12 (8.3)	3/12 (20)	1/33 (3)	5/33 (15)	9/33 (27.2)
	Distal end						
Metatarsal							
	Proximal end						
	Shaft	0/6 (0)	0/60 (0)	2/6 (33.3)	0/18 (0)	3/18 (16.6)	2/18 (11.1)
	Distal end						
Carpals/ Tarsals							
Phalanges							
Other							
ULB**		0/5 (0)	0/5 (0)	1/5 (20)	0/21 (0)	1/21 (4.7)	3/21 (14.2)
ILB**		0/1 (0)	1/1 (100)	0/1 (0)	0/3 (0)	0/3 (0)	0/3 (0)
ILLB**		1/12 (8.3)	1/12 (8.3)	1/12 (8.3)	2/37 (5.4)	6/37 (16.2)	9/37 (24.3)
Indet.		1/20 (5)	0/20 (0)	1/20 (5)	6/99 (6)	6/99 (6)	5/99 (5)
Total		7/115 (6)	9/115 (7.8)	8/115 (6.9)	16/370 (4.3)	43/370 (11.6)	42/370 (11.4)

** ULB, upper limb bones; ILB, intermediate limb bones; ILLB, intermediate lower limb bones.

radius, femur, and tibia). Most of these locations suggest that the marks were the result of defleshing.

Discussion

Butchering activities at BK

The low frequency of tooth marks, and the high percentage of specimens bearing percussion marks and cut marks in all levels but BK4, fit well with experiments modeling primary access to fleshed carcasses by hominins. The abundant distribution of cut marks on all long limb elements and particularly on mid-shafts from upper limb bones, their location on bone sections where only filleting can leave such traces, and the occurrence of cut marks on ventral and dorsal sides of ribs, suggest that hominins were not acquiring resources through passive scavenging of carnivore kills (see Domínguez-Rodrigo et al. (2007) for a comparative discussion). In the latter scenario, shafts (especially those from upper limb bones) would be expected to bear significantly fewer cut marks since these would have been defleshed, and no cut marks would have been found on the ventral sides of ribs, since viscera would have been removed. In this situation, the few cut marks created on the bones would have survived in the areas where muscles are more strongly attached to shafts instead of those areas devoid of muscular insertions or where muscles are easily detached (Domínguez-Rodrigo et al., 2007).

The presence of cut marks and percussion marks on bones from various anatomical areas of size 4 mammals, as well as the abundance of green-fractured specimens from individuals of this size (Fig. 21), together indicate exploitation of *Pelorovis*-sized animals by hominins. This supports previous assertions made by Monahan (1996) and Egeland (2007) that hominins were able to butcher large carcasses. The presence of such modifications and green breakage on bones from several individuals in levels BK2, BK3, and BK4 also suggests that hominins included large animals in their diet repeatedly. This grants further support to Bunn's (1994) findings at Koobi Fora, where cut-marked bones from hippos and giraffes were found in Plio-Pleistocene deposits.

The bulk of taphonomic evidence indicates that hominins were the primary agents in the exploitation of carcasses accumulated at

Table 12
Frequencies of bone surface modifications on each skeletal part from Level 3. Numbers in numerators are for the number of specimens bearing marks; numbers in denominators are the total number of specimens; numbers in parentheses are the percentage. TM, tooth marks; CM, cut marks; PM, percussion marks.

		Small			Middle			Large		
		TM	CM	PM	TM	CM	PM	TM	CM	PM
Skull					0/3 (0)	0/3 (0)	0/3 (0)	0/3 (0)	0/3 (0)	0/3 (0)
Mandible		0/1 (0)	0/1 (0)	0/1 (0)	0/10 (0)	1/10 (10)	0/10 (0)	0/6 (0)	1/6 (16.6)	1/6 (16.6)
Cervical vertebrae										
Thoracic vertebrae					0/2 (0)	0/2 (0)	0/2 (0)	0/1 (0)	0/1 (0)	0/1 (0)
Lumbar vertebrae								0/1 (0)	0/1 (0)	0/1 (0)
Sacral vertebrae										
Vertebrae indet.					0/10 (0)	0/10 (0)	0/10 (0)	0/5 (0)	1/5 (20)	0/5 (0)
Pelvis		0/1 (0)	0/1 (0)	0/1 (0)	0/3 (0)	0/3 (0)	0/3 (0)			
Scapula					0/4 (0)	1/4 (25)	0/4 (0)			
Ribs		1/22 (4.5)	0/22 (0)	0/22 (0)	0/10 (0)	3/10 (30)	0/10 (0)	0/2 (0)	1/2 (50)	0/2 (0)
Humerus										
	Proximal end							0/1 (0)	0/1 (0)	0/1 (0)
	Shaft	0/3 (0)	0/3 (0)	0/3 (0)	0/12 (0)	0/12 (0)	1/12 (8.3)	0/15 (0)	2/15 (13.2)	1/15 (6.6)
	Distal end				0/1 (0)	1/1 (100)	0/1 (0)	0/1 (0)	0/ (0)	0/1 (0)
Radius-ulna										
	Proximal end				1/1 (100)	0/1 (0)	0/1 0)			
	Shaft	0/1 (0)	0/1 (0)	0/1 (0)	0/8 (0)	1/8 (12.5)	2/8 (25)	0/4 (0)	2/4 (50)	1/4 (25)
	Distal end									
Metacarpal										
	Proximal end							0/1 (0)	0/1 (0)	1/1 (100)
	Shaft	0/4 (0)	0/4 (0)	3/4 (75)	0/9 (0)	0/9 (0)	3/9 (33.3)	0/2 (0)	0/2 (0)	1/2 (50)
	Distal end									
Femur										
	Proximal end									
	Shaft				0/9 (0)	3/9 (33.3)	1/9 (11.1)	0/5 (0)	2/5 (40)	1/5 (20)
	Distal end									
Tibia										
	Proximal end									
	Shaft	0/3 (0)	0/3 (0)	1/3 (33.3)	0/11 (0)	0/11 (0)	3/11 (27.2)	0/6 (0)	1/6 (16.6)	1/6 (16.6)
	Distal end									
Metatarsal										
	Proximal end				0/2 (0)	0/2 (0)	0/2 (0)			
	Shaft	0/7 (0)	1/7 (14.2)	1/7 (14.2)	0/10 (0)	0/10 (0)	4/10 (40)	0/1 (0)	0/1 (0)	1/1 (100)
	Distal end									
Carpals/ Tarsals					0/4 (0)	0/4 (0)	0/4 (0)			
Phalanges		0/2 (0)	0/2 (0)	0/2 (0)	0/2 (0)	0/2 (0)	0/2 (0)			
Other										
ULB**		0/5 (0)	1/5 (20)	1/5 (20)	0/14 (0)	0/14 (0)	1/14 (7.1)	0/6 (0)	0/6 (0)	1/6 (16.6)
ILB**		0/1 (0)	0/1 (0)	1/1 (100)	1/3 (33.3)	1/3 (33.3)	0/3 (0)	0/4 (0)	0/4 (0)	0/4 (0)
ILLB**		0/3 (0)	1/3 (33.3)	1/3 (33.3)	1/21 (4.7)	1/21 (4.7)	4/21 (19)	0/5 (0)	0/5 (0)	0/5 (0)
Indet.		0/4 (0)	0/4 (0)	0/4 (0)	0/40 (0)	4/40 (10)	0/40 (0)	0/62 (0)	2/62 (3.2)	0/62 (0)
Total		1/57 (1.7)	3/57 (5.2)	8/57 (14)	3/205 (1.4)	16/205 (7.8)	19/205 (9.2)	0/131 (0)	12/131 (9.1)	9/131 (6.8)

** ULB, upper limb bones; ILB, intermediate limb bones; ILLB, intermediate lower limb bones.

BK. The evenness index for all levels but BK4, and for small mammals in BK3, both of which have very small sample sizes, suggests that dense elements such as crania, mandibles, and long limb bones are evenly represented irrespective of carcass size and archaeological level (Fig. 6). This could represent short-distance transport of carcasses by hominins to the site (Faith et al., 2009). However, when comparative data on modern Hadza carcass transport and evenness indices in their base camps are used, we see that evenness indices for small to large carcasses range from 0.95 (small carcasses) to 0.99 (large carcasses), even if carcasses have been transported over distances of several kilometers (Egeland, 2007). This evenness does not provide any further evidence as to whether these carcasses were transported complete or partially (i.e., bringing only limbs and skulls). We also cannot exclude the possibility that hominins may have transported some ostrich eggs to the site because of the large number of shell fragments ($n = >50$) retrieved across the complete archaeological sequence (BK1 to BK4). Unfortunately, this is difficult to interpret, given the lack of modern referential frameworks for processes that could account for a high accumulation of eggshells in the same place over such an extensive time period, such as the documentation of redundant communal nesting at specific places (Bertram, 1992).

Taphonomic studies of both the excavated assemblage from BK and the collection excavated by Leakey in 1963 reveal a very strong hominin signal in the accumulation and modification of carcasses at this site, in contrast to the signal of carnivores, whose role appears to have been secondary and marginal (Egeland, 2007). This could be used as support for Leakey's (1971) interpretation of BK as a central-place site situated by the edge of a small river and repeatedly occupied and utilized by hominins. Egeland (2007) argued that near-kill locations of modern Hadza foragers are characterized by more uneven assemblages (evenness index = <0.90) than those reported here, which are indistinguishable from those obtained in Hadza assemblages that have been transported to base camps.

BK compared to other Plio-Pleistocene anthropogenic sites with evidence of butchery

Domínguez-Rodrigo (2008a) has argued that, in our current state of taphonomic knowledge, very few archaeofaunal assemblages prior to 1 Ma can be defended as anthropogenic. Of these, the FLK *Zinjanthropus* site (1.84 Ma), also at Olduvai Gorge, shows a similar frequency and anatomical distribution of cut-marked specimens to that reported here for the BK assemblages, and has

Table 13
Frequencies of bone surface modifications on each skeletal part from Level 4. Numbers in numerators are for the number of specimens bearing marks; numbers in denominators are the total number of specimens; numbers in parentheses are the percentage. TM, tooth marks; CM, cut marks; PM, percussion marks.

		Small			Large		
		TM	CM	PM	TM	CM	PM
Skull							
Mandible		0/1 (0)			1/3 (33.3)		
Cervical vertebrae							
Thoracic vertebrae							
Lumbar vertebrae							
Sacral vertebrae							
Vertebrae indet.							
Pelvis					0/1 (0)		
Scapula					0/1 (0)		
Ribs		1/2 (50)			0/5 (0)		
Humerus					0/1 (0)		
	Proximal end				0/2 (0)		
	Shaft	0/1 (0)			0/1 (0)		
	Distal end						
Radius-ulna							
	Proximal end						
	Shaft	0/1 (0)					
	Distal end						
Metacarpal							
	Proximal end						
	Shaft					1/1 (100)	1/1 (100)
	Distal end						
Femur							
	Proximal end						
	Shaft				0/1 (0)		
	Distal end						
Tibia							
	Proximal end						
	Shaft	0/1 (0)				1/6 (16.6)	
	Distal end						
Metatarsal							
	Proximal end						
	Shaft				0/1 (0)		
	Distal end						
Carpals/ Tarsals					1/5 (20)		
Phalanges					0/1 (0)		
Other					0/1 (0)		
ULB**					0/1 (0)		
ILB**					0/1 (0)		
ILLB**					1/6 (16.6)		1/6 (16.6)
Indet.		0/3 (0)			0/32 (0)		
Total		1/10 (10)			3/84 (3.5)	2/84 (2.3)	2/84 (2.3)

** ULB, upper limb bones; ILB, intermediate limb bones; ILLB, intermediate lower limb bones.

also been interpreted as an example of primary access to carcasses by hominins (Bunn and Kroll, 1986; Domínguez-Rodrigo et al., 2007). A much lower frequency of cut-marked bones is documented at the ST4 site at Peninj (Tanzania), which is similar in age to BK. Although they are comparatively few, most cut-marked specimens at ST4 occur on limb shafts, and upper limb bones are the most highly cut-marked appendicular section (Domínguez-Rodrigo et al., 2002), just as is seen at BK and FLK Zinj. Another younger site (slightly older than 1 Ma) is Swartkrans (Member 3) in South Africa. Although this site is a palimpsest, we can say that the few cut-marked bones found there also show a preferential distribution on shafts of meat-bearing bones, i.e., on upper and intermediate long bones, which are more cut-marked than metapodials (Pickering et al., 2004a). In sum, the small number of Plio-Pleistocene sites with meaningful samples of cut-marked bones suggests that hominins had access to fleshed carcasses during this time period, according to currently available analogical frameworks.

Recently, three new sites from Lake Turkana (Kenya) have been added to this short list: FwJj14A, FwJj14B, and GaJi14, which together provide a very large collection of cut-marked bones ($n = 292$) (Pobiner et al., 2008). To compare these fossil collections and the other anthropogenic sites described to modern analogs, only those analogical frameworks created in national parks with minimal anthropogenic disturbance have been used (Domínguez-Rodrigo, 1997a,b), excluding the only alternative analogical framework created in a environment highly altered by human presence (e.g., a ranch where hyenas are killed), and using samples obtained without proper control (Pobiner, 2007). Domínguez-Rodrigo (2008b) emphasized that for any interpretation of cut marks to be valid, data must be linked to analogical premises without distortion. The latter analogical framework misses that crucial point (see critical discussion in Domínguez-Rodrigo, 2008b). When considering these criteria properly, the cut-mark data from the sites analyzed by Pobiner et al. (2008) show a strong similarity to the other early Pleistocene assemblages and to experimental scenarios in which humans have primary access to carcasses, as we can see below.

Studies of cut marks involve several variables. Therefore, the best way to understand each variable's contribution to the total variance of a sample is to use multivariate analysis. If restricted to the original four variables outlined by Domínguez-Rodrigo (1997a,

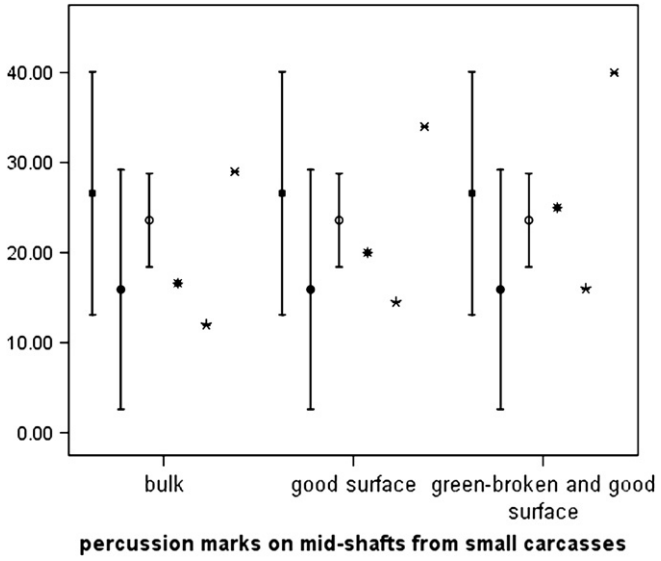

Figure 11. 95% confidence intervals for the frequency of percussion-marked long bone mid-shafts from small carcasses from experimental and BK assemblages. ■, Hammerstone only (Blumenschine, 1995); ●, Human (hammerstone)-to-carnivore (Blumenschine, 1995); ○, Human (hammerstone)-to-carnivore (Capaldo, 1995, 1997, 1998); ✱, BK1; ★, BK2; ×, BK3.

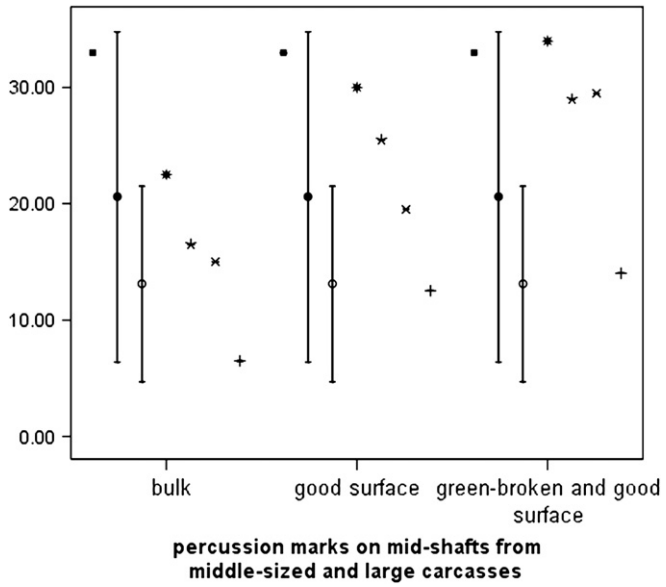

Figure 12. 95% CI (confidence intervals) for the frequency of percussion-marked long bone mid-shafts from middle-sized and large carcasses from experimental and BK assemblages. ■, Hammerstone only (Blumenschine, 1995); ●, Human (hammerstone)-to-carnivore (Blumenschine, 1995); ○, Human (hammerstone)-to-carnivore (Capaldo, 1995, 1997, 1998); ✸, BK1; ★, BK2; ×, BK3; +, BK4.

1999), then a simple principal components analysis (PCA) gives clear results that contrast with those of Pobiner et al. (2008) (Fig. 22). These variables are the total percentage of cut-marked long limb bone specimens, distribution by limb bone type (upper, intermediate, or lower), frequencies per bone portion (epiphyses or shafts), and the ratio of cut-marked meaty limb bone shafts: total cut-marked NISP (Table 14).

Exploratory factor analysis produced a component matrix in which all the variables used had communalities >0.7 and eigenvalues >0.8, with the exception of the lower limb bones. That is, the proportion of variance that each variable had in common with other variables (communality) was fairly high, and the 2-factor solution explained 80% of the variance of the whole sample. If we exclude the outlying sub-variable (frequency of cut marks on lower limbs), the new resulting PCA explained 85% of variance and

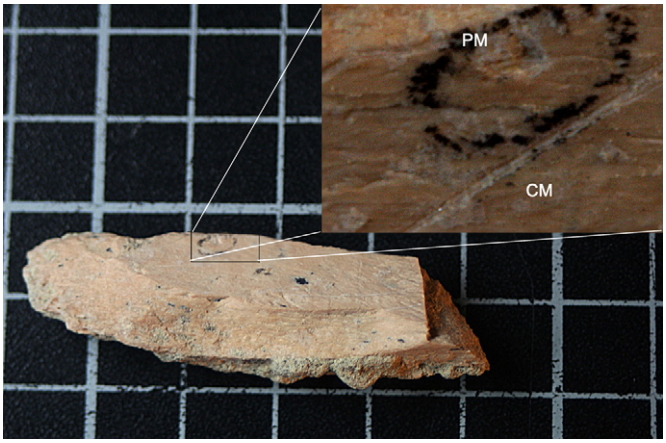

Figure 14. Impact flake from a size 3 bovid limb bone showing cut marks (CM) and percussion marks (PM). Scale = 1 cm.

two factors were obtained. Factor 1 (eigenvalue = 0.65) was composed of a variable set with values >0.8 in the rotated components matrix in the following order of importance according to their total contribution to the factor solution: total percentage of cut-marked long bones, cut-marked mid-shafts, cut-marked upper limb bones, and, to a lesser extent, cut-marked intermediate limb bones (also with a communality >0.7). Factor 2 was composed only of the variable "ratio of cut-marked meat-bearing bone shafts: total cut-marked NISP," with a value in the rotated component matrix of 0.96. Most Plio-Pleistocene sites cluster closer to those control samples that replicate primary access to fleshed carcasses (Fig. 22). They differ from these samples in the Factor 1 values, which are probably lower because of non-significant cut-marked sample sizes for small fauna in some sites, differential bone surface preservation, and more intensive dry breakage, which contrast with the good preservation, and green breakage of the experimental assemblages. Unfortunately, no correction values were used for the archaeological sample set (other than BK), which could produce different regression scores. However, the impact of these taphonomic processes in the final frequency and distribution of cut marks can clearly be seen (Fig. 22).

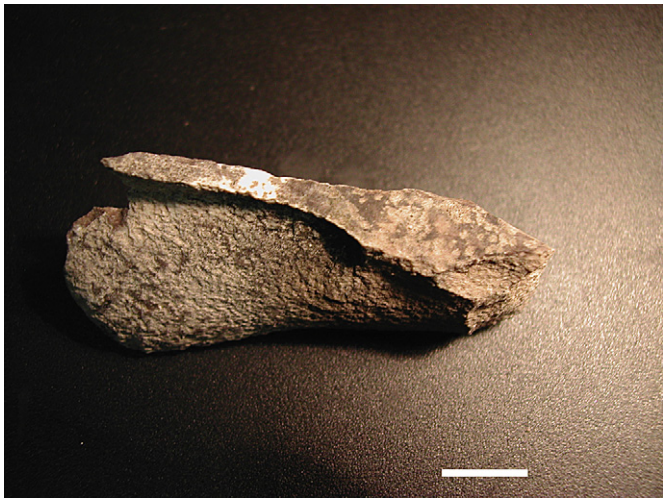

Figure 13. Impact flake from a humerus of a sizes 4–5 carcass in BK3. Scale = 1 cm

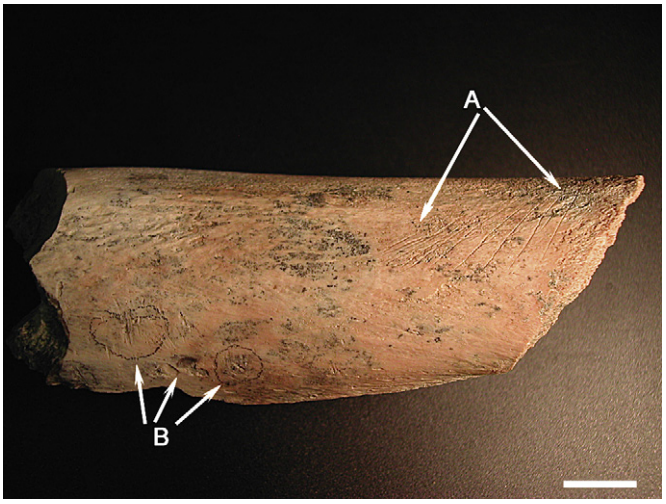

Figure 15. Cut marks (A) and percussion marks (B) on a humeral mid-shaft specimen from BK3. Scale = 1 cm

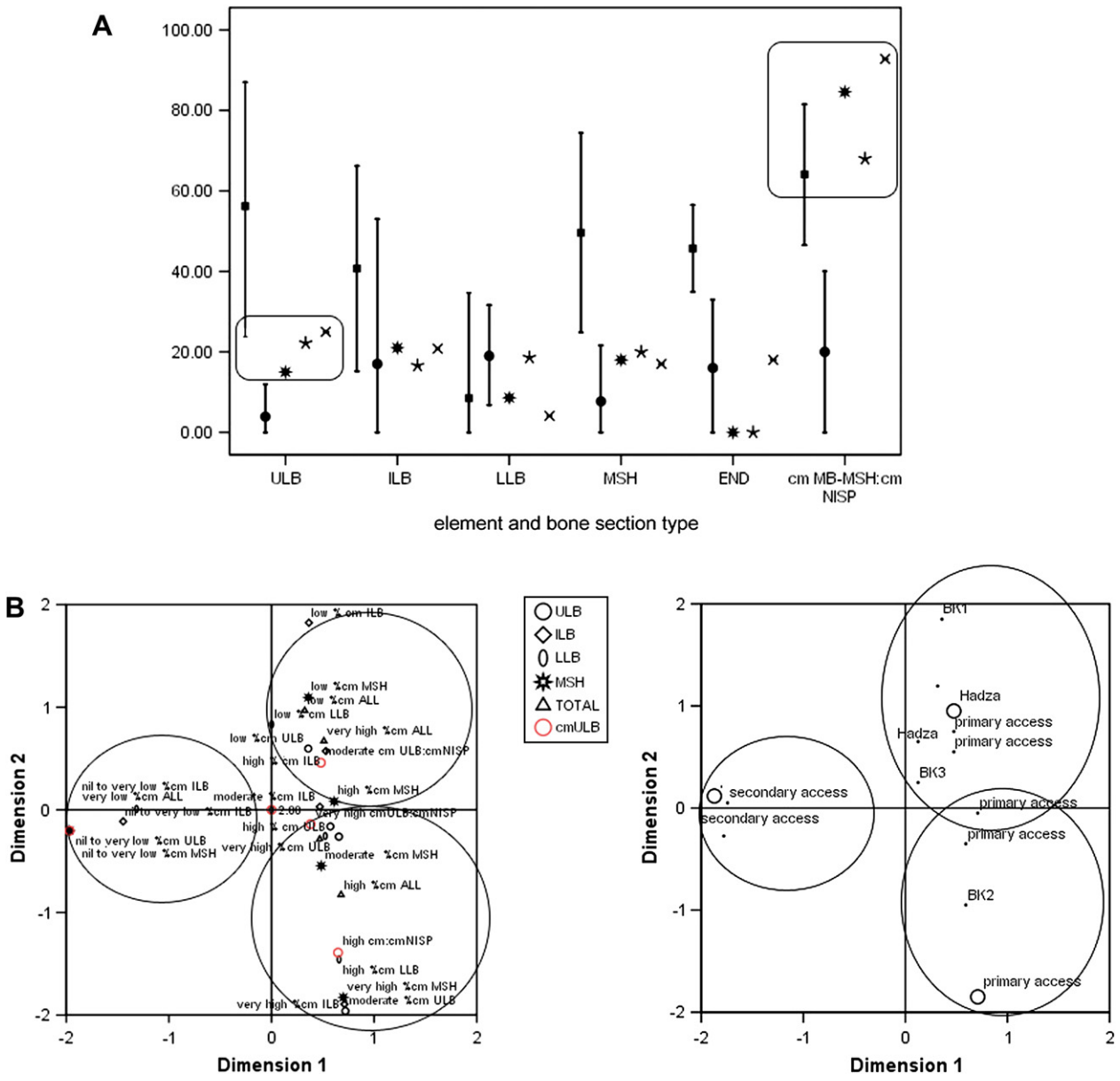

Figure 16. A: Frequencies of cut marks according to long limb element type and bone section, including 95% C.I. analyses for experiments modeling access to fleshed (data from Domínguez-Rodrigo, 1997a) and defleshed (data from Domínguez-Rodrigo, 1997b) carcasses and the cut mark data from the BK site. ■, Human-Hyenid (Domínguez-Rodrigo, 1997a); ●, Felid-Human (Domínguez-Rodrigo, 1997b); ✱, BK1; ★, BK2; ×, BK3. Frequencies were established on modified counts of cut-marked bones according to green-broken pieces and specimens showing good cortical preservation. Data for the last variable (cut-marked meaty-bone mid-shaft: cut-marked limb NISP) was based on proportion of cut-marked specimens from upper + intermediate limb bones versus all cut-marked limb bones. Notice the clustering of the BK data in proximity to the range of experiments modeling primary access (modified from Domínguez-Rodrigo, 1999). This is particularly visible in cut-marked upper limb bones and, especially, on the proportion of cut-marked specimens from meaty bones. B: Multiple Correspondence Analysis (using HOMALS) of experimental, ethnoarchaeological, and archaeological (BK) cut mark data. Experimental and ethnoarchaeological data are from Domínguez-Rodrigo (1997b) for experiments replicating early and late access to carcasses, and from Lupo and O'Connell (2002) for the Hadza assemblages and BK (Tables 9–12). Cut-mark data from BK are only for large-sized animals. The sample of cut-marked bones from small animals was too small to be applied meaningfully in a statistical analysis. The variables used are: ULB, upper limb bones; ILB, intermediate limb bones; LLB, lower limb bones; MSH, mid-shafts; CMULB is the proportion of cut-marked upper limb bones compared to the total cut-marked long bones. (CMULB values have to be used as defined on homogeneous samples, and not samples that show biases in element preservation/retrieval. CMULB values used for the Hadza assemblages were replaced by pairwise/mean values since there is great heterogeneity in the proportion of long limb bones retrieved by Lupo and O'Connell [2002], with very few specimens from humeri and femora compared to radii, tibiae, and metapodials). Each metric variable was turned into multiple categorical variables by dividing the maximum value of the range in each of them by five and assigning categorical values from 1 to 5 accordingly for each 1/5 fraction of percentage: 1, nil to low % cm; 2, low % cm; 3, moderate % cm; 4, high % cm; 5, very high % cm. Two plots are shown for the sake of clarity. The quantifications on the left show the dimensional distribution of the variables used according to their values in the 5-fraction division. The plot on the right shows the distribution of the archaeological sites/levels and the experimental and ethnographic analogs used on the same space. The comparison between plots allows the understanding of the gradient of each variable that influences the location of each site/experimental assemblage. Ovals show the dimensional separation between secondary access (left) and primary access (right), differentiating between ethnographic and experimental analogs replicating regular carcass defleshing (upper right) from experimental analogs replicating intensive carcass defleshing including complete removal of small flesh scraps (lower right).

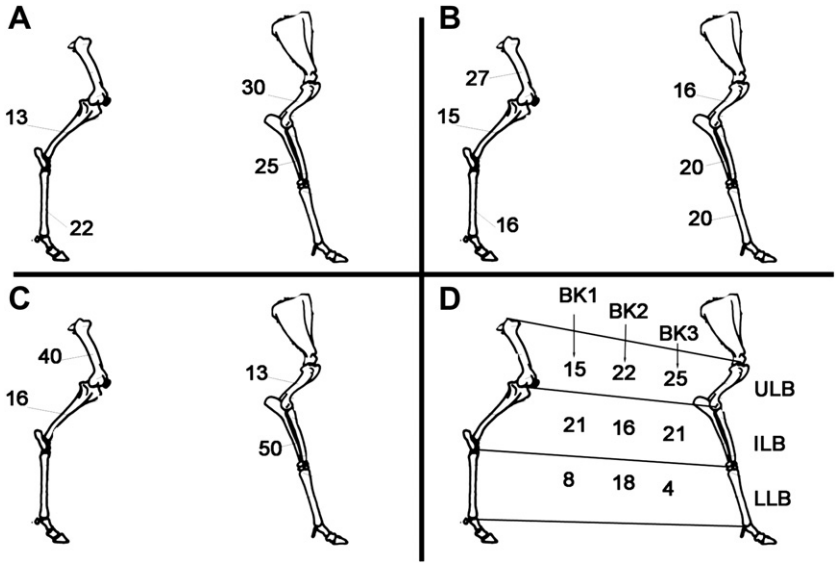

Figure 17. Raw frequencies of cut-marked appendicular specimens from large carcasses -Bunn's sizes 3 and 4 for BK1 (A) and BK2 (B), and size 3 for BK3 (C) - showing lower percentages than would correspond originally given that these frequencies are estimated without correcting for specimens with poor cortical preservation and dry bone breakage (Tables 10–12). When correcting for diagenetic breakage and differential cortical preservation, lumping all data from larger carcasses from BK1, BK2, and BK3 together (D), most cut marks concentrate on upper limb bones (ULB), followed by intermediate limb bones (ILB), and, at a higher distance, by lower limb bones (LLB).

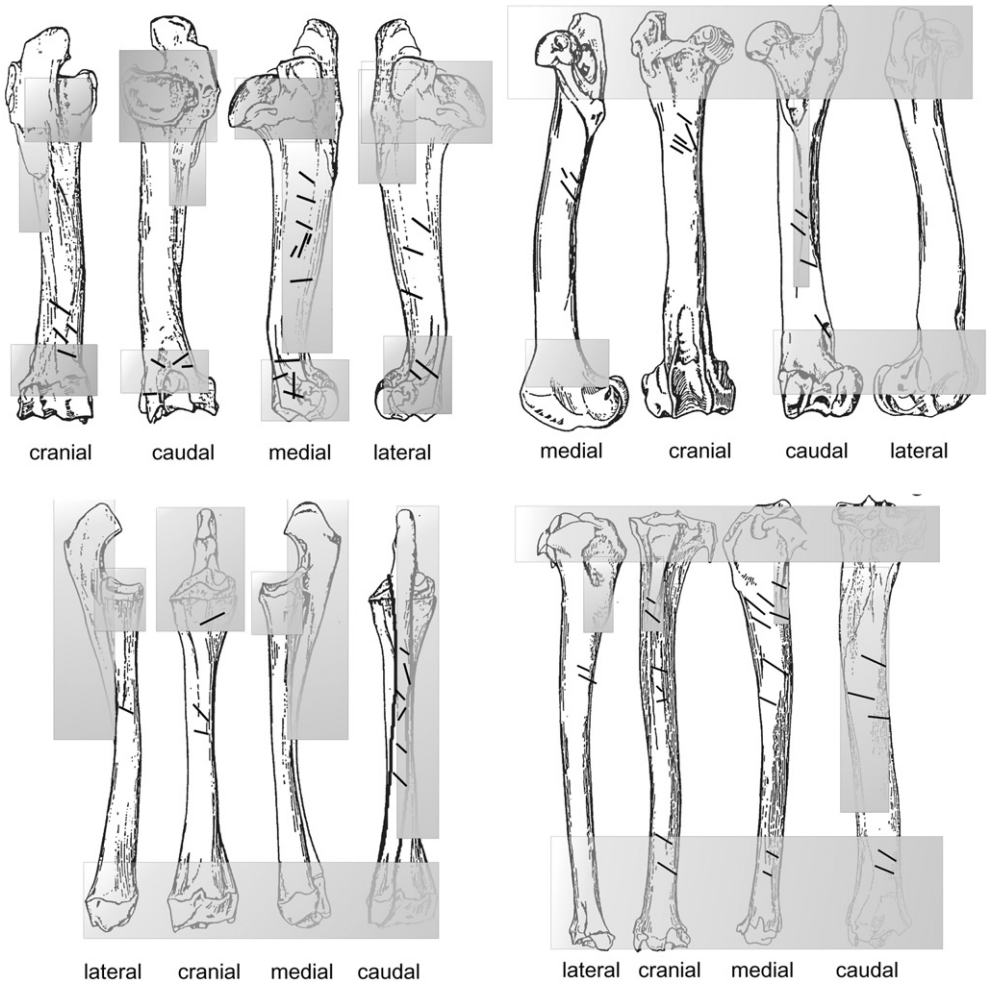

Figure 18. Anatomical distribution of cut marks on limb bones from large carcasses (Bunn's size 3). Specimens bearing cut marks that could not be anatomically placed were left out of this figure. Bones are redrawn from Pales and Lambert (1971). Shaded squares and rectangles show cold zones. The areas without shaded figures correspond to hot zones (see Domínguez-Rodrigo et al., 2007).

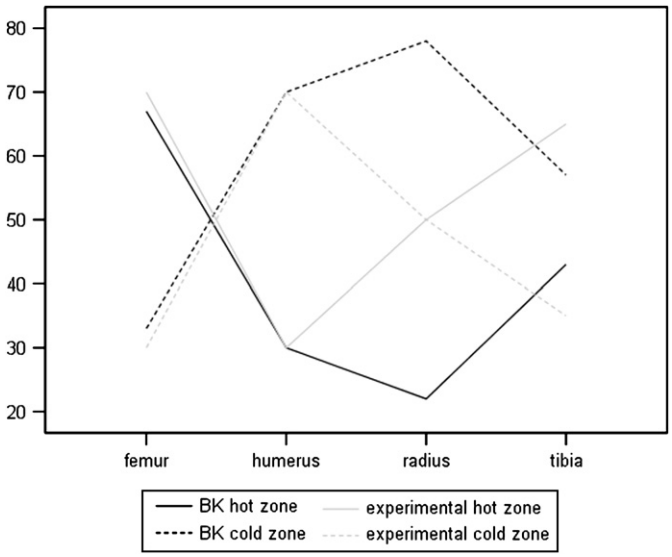

Figure 19. Distribution of cut mark frequencies by element in hot and cold zones from large carcasses (Bunn's size 3) at BK compared with experimental data (see Domínguez-Rodrigo et al., 2007).

The most discriminating variable (explaining 20% of sample variance) is the one that determines Factor 2: "ratio of cut-marked meat-bearing bone shafts: total cut-marked NISP." That is, cut-mark frequencies on shafts from meaty bones make the most substantial difference between the experimental sets reproducing primary and secondary access to carcasses. In this regard, all the archaeological samples are highly loaded in Factor 2 scores and show a high proportion of cut-marked shafts from meat-bearing bones, in clear contrast to experiments replicating secondary access to carcasses.

Figure 20. Humerus epiphyseal fragment showing cut marks on the tendonous insertion of the medial side of the distal epicondyle caused by dismembering.

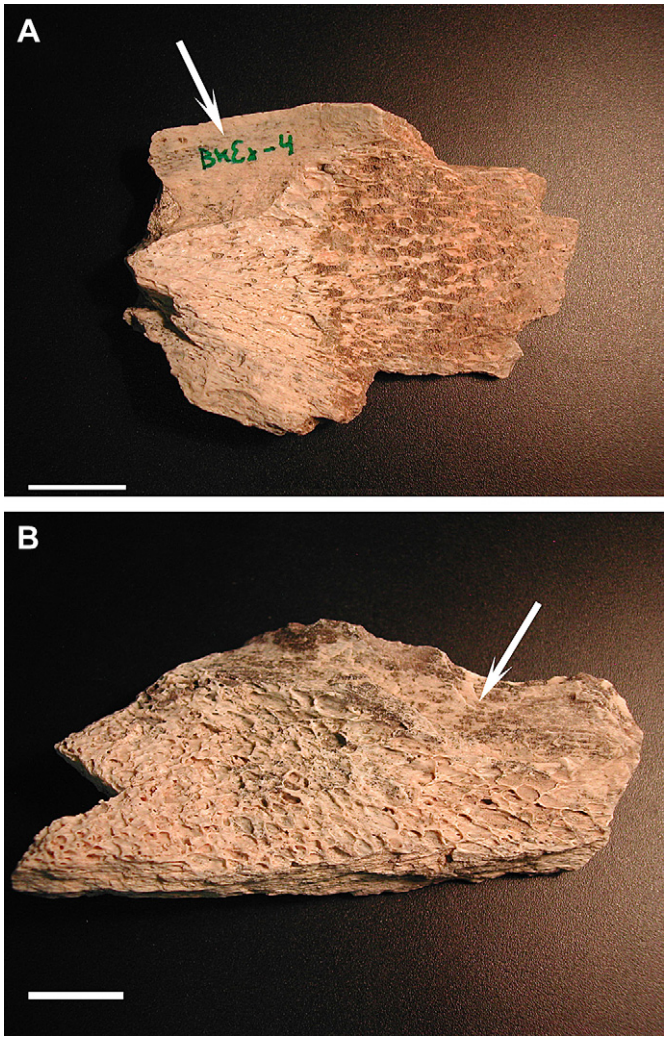

Figure 21. Green-fractured specimens from a humerus (A) and a femur (B) of a size 4 carcass from BK3. Arrows show the scars on the medullary surfaces of green breakage. Scale = 1 cm.

One could further discriminate between primary and secondary access scenarios if more variables were used. For example, if we included presence/absence of secondary disarticulation and evisceration marks, we might have been able to separate experimental sets more clearly and observe a tighter clustering of the archaeological and experimental samples. Here we define primary disarticulation as the initial disarticulation of carcasses at kill sites to be transported as units: skulls, axial units, and whole limb units, as shown by Bunn et al. (1988). We define secondary disarticulation as the dismembering of these units into elements (separating humeri from radii, femora from tibiae, and radii and tibiae from metapodials) as documented in modern foragers' home bases (Bunn, 2001). Some evidence of secondary disarticulation has been found in the form of cut marks on distal epiphyses of humeri and proximal epiphyses of radii from large carcasses at FLK Zinj and ST4. Two distal epiphyses of humeri from BK3 also show cut marks, as noted earlier. Pobiner et al. (2008) described cut-marked carpals and tarsals from FwJj14A (size 3 suid), FwJj14B (size 2 suid), and GaJi14 (size 3 bovid) as the result of separating intermediate limb bones from metapodials; secondary disarticulation was also supported by cut marks on epiphyses of distal humeri and proximal radii. Pobiner et al. (2008) also described cut marks on the ventral sides of ribs of

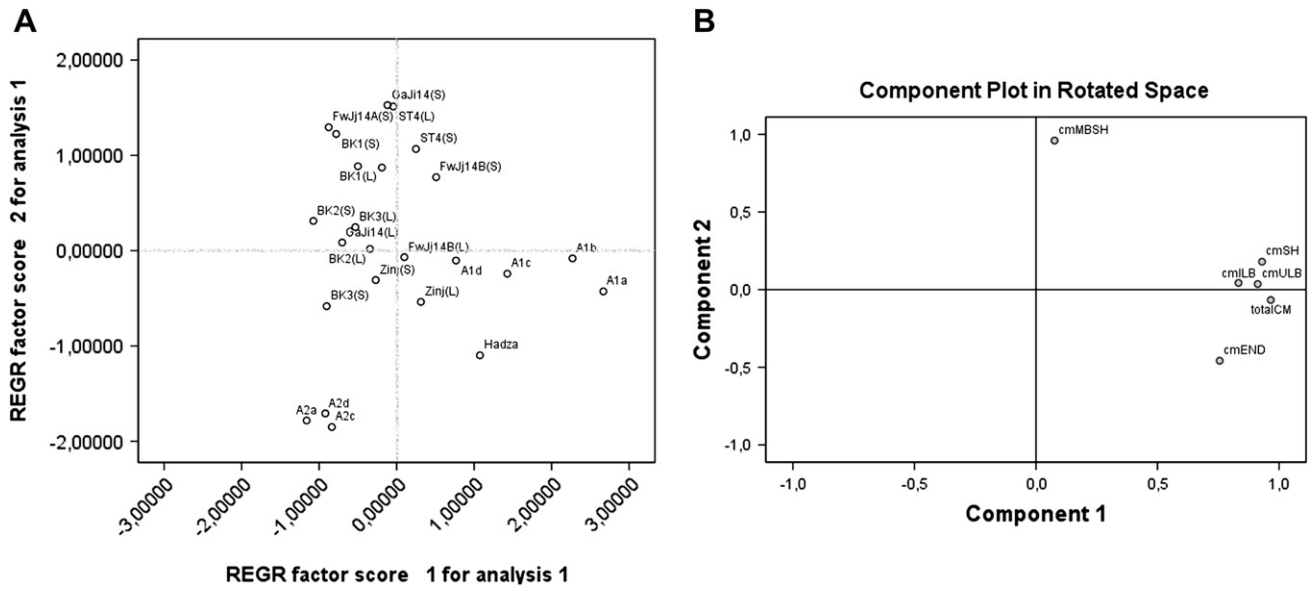

Figure 22. Principal components analysis of the Plio-Pleistocene archaeological assemblages and the experimental samples shown in Table 14. A1, primary access experiments; A2, secondary access experiments (Domínguez-Rodrigo, 1997b). Notice the separate cluster formed by the experiments replicating passive scavenging of defleshed carcasses (A2). The primary access experiments show a wider scatter given that two butchering processes are included: thorough defleshing of all flesh scraps (A1a,b,c) and regular butchering neglecting small flesh scraps (A1d and Hadza) (Domínguez-Rodrigo, 1997a, b; Lupo and O'Connell, 2002). The determinant value is 0.003; the KMO measure of sampling adequacy is 0.74; and the eigenvalues of both factors explain 85% of the sample variance. Key: cmTotal, cut-marked percentage of long bone specimens; cmSH, cut-marked shafts; cmEND, cut-marked epiphyseal fragments; cmULB, cut-marked upper limb bones; cmILB, cut-marked intermediate limb bones; cmMBSH, cut-marked meat-bearing long bone shafts. For the regression factor score: (S), small carcasses (Bunn's sizes 1 and 2); (L), large carcasses (Bunn's size 3).

Table 14
Distribution of frequencies of cut-marked long bones according to element type and bone section. Numbers in parentheses are for percentages.

Small carcasses	Site							
		Total%CM	cmULB	cmILB	cmLLB	cmENDS	cmSHAFTS	cmMBMSH: cmNISP*
	FwJj14A[a]	1/13 (7.6)	1/7 (14.3)	0/3 (0)	0/3 (0)	0/6 (0)	1/7 (14.2)	1/1 (100)
	FwJj14B[a]	3/12 (25)	1/5 (20)	1/2 (50)	1/5 (20)	0/3 (0)	3/9 (33.3)	2/3 (66.6)
	GaJi14[a]	3/15 (20)	0/5 (0)	3/10 (30)	0/0 (0)	0/5 (0)	3/10 (30)	3/3 (100)
	FLK Zinj[b]	27/81 (15)	10/50 (20)	13/66 (20)	4/65 (6.1)	12/55 (21.8)	16/126 (12)	15/27 (55.5)
	Peninj ST4[c]	13/70 (18.5)	9/27 (33.3)	9/31 (29)	1/16 (6.2)	3/23 (13)	10/42 (23.8)	12/13 (92)
	BK1	3/24 (12.5)	0/15 (0)	2/9 (22.2)	0/9 (0)	0/0 (0)	2/33 (6)	2/2 (100)
	BK2	3/50 (6)	0/13 (0)	2/17 (11.7)	1/22 (4.5)	0/0 (0)	3/41 (7.3)	2/3 (66.6)
	BK3	3/20 (15)	1/8 (12.5)	0/5 (0)	2/14 (14.2)	0/0 (0)	3/27 (11.1)	1/3 (33.3)
Larger carcasses	Site							
		Total%CM	cmULB	cmILB	cmLLB	cmENDS	cmSHAFTS	cmMBMSH: cmNISP
	FwJj14A[a]	21/125 (16.8)	5/33 (15.2)	12/45 (26.6)	4/47 (8.5)	1/31 (3.2)	20/94 (21.3)	17/21 (81)
	FwJj14B[a]	16/76 (21.1)	7/29 (24.2)	4/19 (21)	5/28 (17.8)	2/8 (25)	14/68 (21)	10/16 (62.5)
	GaJi14[a]	19/170 (12)	6/49 (12.3)	7/84 (8.3)	6/37 (16.2)	3/31 (9.6)	16/139 (11.5)	12/19 (63.2)
	FLK Zinj[b]	72/319 (22.6)	26/102 (25.4)	37/160 (23.1)	7/57 (12.2)	27/58 (46.6)	45/261 (17.2)	45/72 (62.5)
	Peninj ST4[c]	4/29 (13.7)	5/12 (41.6)	2/11 (18)	0/6 (0)	0/9 (0)	4/18 (22.2)	7/7 (100)
	BK1	14/78 (18)	3/18 (16.6)	7/49 (14.2)	3/36 (8.3)	0/4 (0)	13/103 (12.6)	11/13 (84.6)
	BK2	37/140 (26)	9/63 (14.2)	8/51 (15.6)	8/43 (18.6)	0/0 (0)	31/194 (16)	16/31 (52)
	BK3	11/64 (17)	4/36 (11.1)	2/23 (8.6)	0/21 (0)	1/4 (25)	5/80 (6.2)	5/6 (83.3)
Experimental controls								
Access to fleshed carcasses[d]								
	H1S1/2a	22/40 (55)	11/16 (68.7)	8/13 (61.5)	3/11 (27.2)	10/18 (55.5)	12/22 (54.5)	11/22 (50)
	H1S1/2b	13/24 (54)	10/14 (71)	3/9 (33.3)	0/1 (0)	6/14 (42.8)	6/10 (60)	7/13 (54)
	H1S1/2c	13/31 (42)	8/17 (47)	5/12 (41.6)	1/2 (50)	7/16 (43.7)	5/15 (33.3)	8/13 (61.5)
	H1S1/2d	14/48 (29)	7/21 (33.3)	6/16 (37.5)	1/11 (9)	5/14 (35.7)	9/34 (26.5)	9/14 (64.2)
	Hadza[e]	152/441(34.4)	33/86 (38.3)	80/218 (36.6)	39/137 (28.4)	72/125 (57.6)	80/316 (25.3)	66/152 (44)
Secondary access to defleshed carcasses[d]								
	H2S1/2/3a	5/67 (7)	0/29 (0)	2/25 (8)	3/13 (23)	4/36 (11.1)	1/31 (3.2)	0/5 (0)
	H2S1/2/3c	7/61 (11.4)	2/23 (8.6)	3/22 (13.6)	2/16 (12.5)	6/36 (16.6)	1/25 (4)	0/7 (0)
	H2S1/2/3d	6/57 (10.5)	1/22 (4.5)	2/20 (10)	3/15 (20)	4/35 (11.4)	2/22 (9)	0/6 (0)

ULB, upper limb bones; ILB, intermediate limb bones; LLB, lower limb bones.
* cmMBSH:cmNISP: cut-marked meat/-bearing shafts:cut-marked number of identifiable specimens.
[a] Data from Pobiner et al. (2008: Table 8).
[b] Data from Domínguez-Rodrigo et al. (2007).
[c] Data from Domínguez-Rodrigo et al. (2002).
[d] Data from Domínguez-Rodrigo (1997b).
[e] Data from Lupo and O'Connell (2002).

large carcasses, which suggest evisceration. This has also been documented among large carcasses at BK2, BK3, and Zinj, and would be expected in a situation of primary access by hominins to complete carcasses. Until this important information is published with quantitative data, no statistical test can be reliably applied.

Conclusions

The taphonomic data reported here suggest that hominins were the primary agent of modification and consumption of small and middle-sized carcasses at the BK site. These data include: an abundance of green fractures; breakage planes with either acute or obtuse angles indicative of dynamic loading; measurements of the complete notches showing large and shallow shapes (again indicative of hammerstone percussion); a high frequency of single notches compared to double-opposing and double overlapping notches (indicating a lack of carnivore-made notches); low frequencies of tooth-marked bones; an abundance of percussion marks (BK has the highest frequency of marks of any Lower Pleistocene site); and a high frequency of cut marks found on elements and bone sections that would have already been defleshed by carnivores if they had had primary access. Traces of hominin modifications on size 4 carcasses (*Pelorovis*) in BK3 and BK4 also suggest exploitation of larger game.

These results concur with Monahan's (1996) interpretations of the site in which early carcass acquisition, a focus on long bone meat instead of marrow, a focus on larger (size 3–4) carcasses, and exploitation of a variety of carcass resources by hominins, were inferred. It differs from Monahan's study in a much higher identification of cut-marked specimens, a significantly lower frequency of tooth-marked specimens when compared to cut-marked bones, a higher frequency of hammerstone-percussed specimens, a clearer contrast between limb and axial cut-marked specimens (with the former being much more abundant as at FLK Zinj), a more contrasted frequency of cut-marked specimens when comparing upper, intermediate, and lower limb bones, and differences in the skeletal profiles. The present results support Monahan's (1996) assertion that BK represents a focal point, but the contrast that he suggested between BK and FLK Zinj, with the former resembling more modern foragers' focal points (i.e., home bases) is not supported and still needs to be tested with further data.

The assemblage at BK appears to reflect a place where multiple butchery events took place, but otherwise its function is still not completely known. A larger area should be exposed in order to make this site comparable to other sites such as FLK Zinj. However, the present study indicates that BK should be added to the small number of Plio-Pleistocene sites where hominins contributed to the faunal assemblage and where primary access to carcasses can be inferred through taphonomic analyses (Bunn, 1982; Domínguez-Rodrigo, 2002; Domínguez-Rodrigo et al., 2002, 2007; Pickering et al., 2004a,b). The high frequencies of cut marks and percussion marks from such a small excavation suggest that BK could potentially contain the largest number of hominin-modified bones of all known Lower Pleistocene sites in Africa. If one 10 m $\times$ 3 m trench has produced a sample of hominin-modified bone that is comparable to the 300 m^2 excavation at FLK Zinj, what could a similarly large excavation at BK produce? This calls for future research at the site in order to expand the excavation area. In addition, this would allow the collection of more information on site functionality, given its re-occupation over such a vast amount of time.

Acknowledgements

We appreciate permission granted by the Tanzanian Commission for Science and Technology (COSTECH) and the Department of Antiquities to conduct research at Olduvai Gorge. We are also thankful to the special commission created by the Tanzanian Ministry of Tourism and Cultural Resources, COSTECH, and the Department of Antiquities for supporting our work. MDR also wishes to thank M. Prendergast for her assistance in editing this paper and for her invaluable suggestions and support. We appreciate the comments made by S. Leigh, the associate editor, and three reviewers of an earlier draft of this paper. Special thanks are for J. Blumenfeld for her help in the final edition of the manuscript. This research was funded by the Spanish Ministry of Science and Technology under grant HUM2007-63815 and by the Spanish Ministry of Culture. Support was also provided by the Fundación Conjunto Paleontológico de Teruel.

References

Alcántara, V., Barba, R., Barral, J., Crespo, A., Eiriz, A., Falquina, A., Herrero, S., Ibarra, A., Megías, M., Pérez, M., Pérez, V., Rolland, J., Yravedra, J., Vidal, A., Domínguez-Rodrigo, M., 2006. Determinación de procesos de fractura sobre huesos frescos: Un sistema de análisis de los ángulos de los planos de fracturación como discriminador de agentes bióticos. Trabajos de Prehistoria 63 (1), 25–38.

Barba, R., Domínguez-Rodrigo, M., 2005. The taphonomic relevance of the analysis of bovid long limb bone shaft features and their application to element identification: study of bone thickness and morphology of the medullary cavity. J. Taphonomy 3, 17–42.

Barba, R., Domínguez-Rodrigo, M., 2008. Nueva aproximación al estudio de las marcas de corte: Definición de 'zonas calientes' como indicador de un consumo inicial de las carcasas por parte de los homínidos. Aplicación al conjunto de FLK Zinj (Olduvai). Complutum 19, 9–24.

Bertram, B.C., 1992. The Ostrich Communal Nesting System. Princeton University Press, Princeton.

Blumenschine, R.J., 1988. An experimental model of the timing of hominin and carnivore influence on archaeological bone assemblages. J. Archaeol. Sci. 15, 483–502.

Blumenschine, R.J., 1995. Percussion marks, tooth marks and the experimental determinations of the timing of hominin and carnivore access to long bones at FLK *Zinjanthropus*, Olduvai Gorge, Tanzania. J. Hum. Evol. 29, 21–51.

Blumenschine, R.J., Selvaggio, M.M., 1988. Percussion marks on bone surfaces as a new diagnostic of hominin behavior. Nature 333, 763–765.

Blumenschine, R.J., Selvaggio, M.M., 1991. On the marks of marrow bone processing by hammerstones and hyenas: their anatomical patterning and archaeological implications. In: Clark, J.D. (Ed.), Cultural Beginnings: Approaches to Understanding Early Hominin Life Ways in the African Savanna. R. Habelt. GMBH, Bonn, pp. 17–32.

Bunn, H.T., 1981. Archaeological evidence for meat-eating by Plio-Pleistocene hominins from Koobi Fora, Kenya. Nature 291, 574–577.

Bunn, H.T., Meat-Eating And Human Evolution: Studies on the Diet and Subsistence Patterns Of Plio-Pleistocene Hominins in East Africa. Ph. D. Dissertation. University of California, Berkeley, 1982.

Bunn, H.T., 1994. Early Pleistocene hominin foraging strategies along the ancestral Omo River at Koobi Fora, Kenya. J. Hum. Evol. 27, 247–266.

Bunn, H.T., 2001. Hunting, power scavenging, and butchering by Hadza foragers and by Plio-Pleistocene *Homo*. In: Stanford, C.B., Bunn, H.T. (Eds.), Meat-Eating and Human Evolution. Oxford University Press, Oxford, pp. 199–218.

Bunn, H.T., 2007. Butchering backstraps and bearing backbones: insights from the Hadza foragers and implications for Paleolithic archaeology. In: Pickering, T.R., Schick, K., Toth, N. (Eds.), Breathing Life into Fossils: A Tribute to the Career of C.K. Brain. CRAFT Press, Indiana, pp. 269–280.

Bunn, H.T., Kroll, E.M., 1986. Systematic butchery by Plio-Pleistocene hominins at Olduvai Gorge, Tanzania. Curr. Anthropol. 27, 431–452.

Bunn, H.T., Bartram, L.E., Kroll, E.M., 1988. Variability in bone assemblage formation from Hadza hunting, scavenging, and carcass processing. J. Anthropol. Arch. 7, 412–457.

Capaldo, S.D., Inferring Hominin and Carnivore Behavior from Dual-Patterned Archaeological Assemblages. Ph. D. Dissertation, Rutgers University, 1995.

Capaldo, S.D., 1997. Experimental determinations of carcass processing by Plio-Pleistocene hominins and carnivores at FLK 22 (*Zinjanthropus*), Olduvai Gorge, Tanzania. J. Hum. Evol. 33, 555–597.

Capaldo, S.D., 1998. Methods, marks and models for inferring hominin and carnivore behaviour. J. Hum. Evol. 35, 323–326.

Capaldo, S.D., Blumenschine, R.J., 1994. A quantitative diagnosis of notches made by hammerstone percussion and carnivore gnawing in bovid long bones. Am. Antiq. 59, 724–748.

Cleghorn, N., Marean, C.W., 2004. Distinguishing selective transport and in situ attrition: a critical review of analytical approaches. J. Taphonomy 2, 43–67.

Delpeche, F., Villa, P., 1993. Activités de chasse et boucherie dans la grotte des Eglises. In: Desse, J., Audoin-Rouzeau, F. (Eds.), Exploitation des Animaux

Sauvages a Travers le Temps. IV, Colloque International de l'Homme et l'Animal. Editions. APDCA, pp. 79–102.
Domínguez-Rodrigo, M., 1997a. Meat eating by early hominids at FLK Zinj 22 site, Olduvai Gorge, Tanzania: an experimental approach using cut-mark data. J. Hum. Evol. 33, 669–690.
Domínguez-Rodrigo, M., 1997b. A reassessment of the study of cut mark patterns to infer hominin manipulation of fleshed carcasses at the FLK Zinj 22 site, Olduvai Gorge, Tanzania. Trabajos de Prehistoria 54, 29–42.
Domínguez-Rodrigo, M., 1999. Distinguishing between apples and oranges: the application of modern cut-mark studies to the Plio-Pleistocene (a reply to Monahan). J. Hum. Evol. 37, 793–800.
Domínguez-Rodrigo, M., 2002. Hunting and scavenging by early humans: the state of the debate. J. World Prehist. 16, 1–54.
Domínguez-Rodrigo, M., 2008a. Are all Oldowan sites palimpsests? If so, what can they tell us about hominin carnivory. In: Hovers, E., Braun, D. (Eds.), Interdisciplinary Approaches to Understanding the Oldowan. Springer, New York, pp. 129–147.
Domínguez-Rodrigo, M., 2008b. Conceptual premises in experimental design and their bearing on the use of analogy: an example from experiments on cut marks. World Archaeol. 40, 67–82.
Domínguez-Rodrigo, M., Barba, R., 2006. New estimates of tooth marks and percussion marks from FLK Zinj, Olduvai Gorge (Tanzania): the carnivore-hominin-carnivore hypothesis falsified. J. Hum. Evol. 50, 170–194.
Domínguez-Rodrigo, M., Barba, R., Egeland, C.P., 2007. Deconstructing Olduvai. Springer, New York.
Domínguez-Rodrigo, M., de la Torre Sáinz, I., Luque, L., Alcalá, L., Mora, R., Serrallonga, J., Medina, V., 2002. The ST Site Complex at Peninj, West Lake Natron, Tanzania: implications for early hominid behavioural models. J. Archaeol. Sci. 29, 639–665.
Egeland, C.P., Zooarchaeological and Taphonomic Perspectives on Hominin and Carnivore Interactions at Olduvai Gorge. Ph. D. Dissertation, Indiana University, 2007.
Egeland, C.P., Domínguez-Rodrigo, M., 2008. Taphonomic perspectives on hominin site use and foraging strategies during the Bed II times at Olduvai Gorge, Tanzania. J. Hum. Evol. 55, 1031–1052.
Faith, J.T., Gordon, A.D., 2007. Skeletal element abundances in archaeofaunal assemblages: Economic utility, sample size, and assessment of carcass transport strategies. J. Archaeol. Sci. 34, 872–882.
Faith, J.T., Domínguez-Rodrigo, M., Gordon, A.D., 2009. Long-distance carcass transport at Olduvai Gorge? A quantitative examination of Bed I skeletal element abundances. J. Hum. Evol. 56, 247–256.
Hay, R., 1976. Geology of the Olduvai Gorge. University of California Press, Berkeley.
Leakey, M.D., 1971. Olduvai Gorge, Vol. 3. Excavations in Bed I and II, 1960-63. Cambridge University Press, Cambridge.
Leakey, M.D., 1976. A summary and discussion of the archaeological evidence from Bed I and Bed II, Olduvai Gorge, Tanzania. In: Isaac, G.L., Mc Cown, E.R. (Eds.), Human Origins: Louis Leakey and the East African Evidence. W.A. Benjamin, Inc., Menlo Park, pp. 431–460.
Lupo, K.D., O'Connell, J.F., 2002. Cut and tooth mark distributions on large animal bones: Ethnoarchaeological data from the Hadza and their implications for current ideas about early human carnivory. J. Archaeol. Sci. 29, 85–109.
Lyman, R., 1994. Vertebrate Taphonomy. Cambridge University Press, Cambridge.
Marean, C.W., 1998. A critique of the evidence for scavenging by Neanderthals and early modern humans: new data from Kobeh Cave (Zagros Mountains, Iran), Die Kielders Cave 1 layer 10, South Africa. J. Hum. Evol. 35, 111–136.
Marean, C.W., Spencer, L.M., 1991. Impact of carnivore ravaging of bone in archaeological assemblages. J. Archaeol. Sci. 18, 677–694.
Marean, C.W., Cleghorn, N., 2003. Large mammal skeletal element transport: applying foraging theory in a complex taphonomic system. J. Taphonomy 1, 15–42.
Marean, C.W., Spencer, L.M., Blumenschine, R.J., Capaldo, S.D., 1992. Captive hyaena bone choice and destruction, the Schlepp effect and Olduvai archaeofaunas. J. Archaeol. Sci. 19, 101–121.
Marean, C.W., Abe, Y., Nilssen, P., Stone, E., 2001. Estimating the Minimum Number of Skeletal Elements (MNE) in zooarchaeology: a review and a new image-analysis GIS approach. Am. Antiq. 66, 333–348.
Marean, C.W., Domínguez-Rodrigo, M., Pickering, T.R., 2004. Skeletal element equifinality in zooarchaeology begins with method: the evolution and status of the 'shaft critique.'. J. Taphonomy 2, 69–98.
Monahan, C.M., 1996. New zooarchaeological data from Bed II, Olduvai Gorge, Tanzania: implications for hominin behavior in the Early Pleistocene. J. Hum. Evol. 31, 93–128.
Münzel, S.C., 1988. Quantitative analysis and archaeological site interpretation. Archaeozoologia 2, 93–110.
Nilssen, P.J., An Actualistic Butchery Study in South Africa and Its Implications for Reconstructing Hominin Strategies of Carcass Acquisition and Butchery in the Upper Pleistocene and Plio-Pleistocene. Ph.D. Dissertation, University of Cape Town, 2000.
Pales, L., Lambert, C., 1971. Mammifères du Quaternaire: Les membres (herbivores). Centre National de Recherche Scientifique, Paris VII.
Patou-Mathis, M.E., Contribution a l'étude des mammifères des couches supérieures de la Grotte du Lazaret. M.A. Thesis, Université de la Sorbonne, 1984.
Patou-Mathis, M.E., 1985. La fracturation des os longs de grands mammifères: Élaboration d'un lexique et d'une fiche type. Outillage peu élabore en os et en bois de cervidés. Artefacts 1, 11–22.
Pickering, T.R., Marean, C., Domínguez-Rodrigo, M., 2003. Importance of limb bone shaft fragments in zooarchaeology: A response to 'On in situ attrition and vertebrate body part profiles' (2002), by M.C. Stiner. J. Archaeol. Sci. 30, 1469–1482.
Pickering, T.R., Domínguez-Rodrigo, M., Egeland, C., Brain, C.K., 2004a. New data and ideas on the foraging behaviour of Early Stone Age hominins at Swartkrans Cave, South Africa. S. Afr. J. Sci. 100, 215–219.
Pickering, T.R., Domínguez-Rodrigo, M., Egeland, C., Brain, C.K., 2004b. Beyond leopards: tooth marks and the contribution of multiple carnivore taxa to the accumulation of the Swartkrans member 3 fossil assemblage. J. Hum. Evol. 46, 595–604.
Pickering, T.R., Domínguez-Rodrigo, M., Egeland, C., Brain, C.K., 2005. The contribution of limb bone fracture patterns to reconstructing early hominin behavior at Swartkrans Cave (South Africa): archaeological application of a new analytical method. Intl. J. Osteoarchaeol 15, 247–260.
Pickering, T.R., Egeland, C., Domínguez-Rodrigo, M., Brain, C.K., Schnell, A., 2008. Testing the 'shift in the balance of power' hypothesis at Swartkrans, South Africa: Hominin cave use and subsistence behavior in the Early Pleistocene. J. Anthropol. Arch. 27, 30–45.
Pobiner, B., Hominin-Carnivore Interactions: Evidence from Modern Carnivore Bone Modification and Early Pleistocene Archaeofaunas (Koobi Fora, Kenya; Olduvai Gorge, Tanzania). Ph. D. Dissertation, Rutgers University, 2007.
Pobiner, B.L., Rogers, M., Monahan, C., Harris, J.W.K., 2008. New evidence for hominin carcass processing strategies at 1.5 Ma, Koobi Fora, Kenya. J. Hum. Evol. 55, 103–130.
Villa, P., Mahieu, E., 1991. Breakage patterns of human long bones. J. Hum. Evol. 21, 27–48.
Wings, O., 2003. Observations on the release of gastroliths from ostrich chick carcasses in terrestrial and aquatic environments. J. Taphonomy 2, 97–104.
Yravedra, J., Domínguez-Rodrigo, M., 2009. The shaft-based methodological approach to the quantification of long limb bones and its relevance to understanding hominin subsistence in the Pleistocene: Application to four Paleolithic sites. J. Quatern. Sci. 24, 85–96.