

## The contribution of limb bone fracture patterns to reconstructing early hominid behavior at Swartkrans Cave (South Africa): archaeological application of a new analytical method

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### **Abstract:**

Recently, Alcántara García *et al.* (in press) presented a new method and criteria for distinguishing between fractures imparted by hominid hammerstone percussion and carnivores chewing on ‘green’ limb bones of ungulates. The method uses a combination of fracture plane and fracture angle data that are useful for elucidating the relative role of hominids in the accumulation of prehistoric archaeofaunas, especially when employed in concert with other classes of taphonomic data. We briefly summarise the method and apply it to the ungulate limb bone subassemblage from Swartkrans Member 3, a *c.* 1.0 million year old site from South Africa that preserves Early Stone Age lithic artefacts, hominid fossils, and an abundant mammalian fauna with cutmarked, hammerstone-percussed and burned bone specimens. Results of the fracture pattern analysis corroborate indications from other lines of taphonomic data that there was minimal carnivore–hominid interdependence in the formation of the fauna, and that carnivores were probably responsible for the majority of the bone collection in Member 3. However, we also document a significant hominid influence on assemblage formation, a finding that expands and refines our understanding of large animal carcass foraging by hominids in southern Africa during the early Pleistocene.

**Keywords:** zooarchaeology | taphonomy | limb bone shaft | ‘green’ bone fracture | hominid | carnivore | Swartkrans

### **Article:**

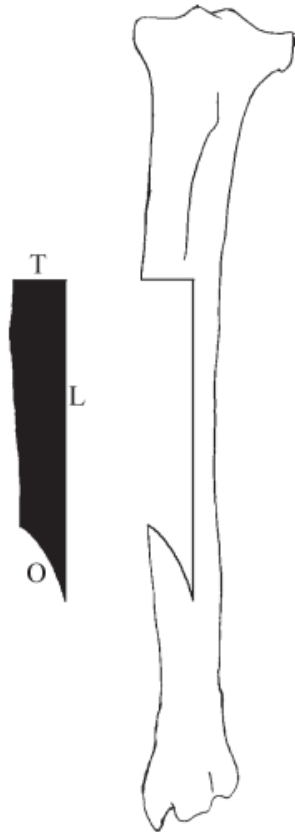
### **Introduction**

Because most archaeofaunas are fragmented to at least some extent, the analysis of limb bone fracture patterns has often featured in zooarchaeological studies of Pliocene and Pleistocene assemblages from both the Old and New Worlds (e.g. Pei, 1938; Dart, 1957; Sadek-Kooros, 1972, 1975; Bonnicksen, 1973, 1975, 1979; Irving & Harington, 1973; Ghosh, 1974; Read-Martin & Read, 1975; Morlan, 1980, 1983, 1984, 1988; Bunn, 1983, 1989; Haynes, 1983; Johnson, 1983, 1985a,b; Patou Mathis, 1985; Irving et al., 1989; Patou Mathis, 1993; Pérez Ripoll, 1993; Rueda, 1993; Anconetani et al., 1996; Mateos Cachorro 1999, 2000).<sup>1</sup> Prominent among this body of work is Villa & Mahieu's (1991) study of limb bone fracture in anatomically modern human skeletons from French archaeological sites, research that corroborated and expanded that of earlier workers (e.g. Myers et al., 1980; Johnson, 1985) and anticipated that of others (e.g. Martínez, 1998; Outram, 2001). Villa & Mahieu (1991) concentrated on five limb bone fracture attributes: fracture outline (the shape of the fracture); proportion of original shaft circumference remaining; shaft fragmentation; shaft breadth to length ratios; and, most relevant to the present study, fracture angle (i.e. that 'angle formed by the fracture surface and the bone cortical surface'; Villa & Mahieu, 1991: 34). Importantly, fracture angles of limb bones that are broken when 'green' (i.e. before significant loss of a bone's organic fraction and its desiccation) are usually either acute or obtuse. This is in contrast to limb bones that are broken when dry, which usually preserve fracture angles that are right. Capaldo & Blumenshine (1994: 763) supplemented this work by investigating variability in fracture angles imparted on green bone by different taphonomic agents, finding that angles on bone fragments 'removed from percussion notches are more obtuse than those removed from carnivore notches, which are closer to perpendicular'.

Another way in which zooarchaeologists have considered fracture patterns relevant to the current study regards planes of fracture. Conventionally, it is agreed that with reference to its long axis, any broken limb bone fragment can possess one or more the following fracture planes: longitudinal, transverse and oblique (e.g. Sadek-Kooros, 1972, 1975; Shipman et al., 1981; Bridault, 1984; Patou Mathis, 1984; Johnson, 1985a; Todd, 1987; Alcalá & Martin, 1988; Morales, 1988; Gifford-Gonzalez, 1989; Marshall, 1989; Anconetani, 1996) (Figure 1). Gifford-Gonzalez (1989) provided clear definitions of fractures that are longitudinal (fractures parallel to the long axis of the bone) and transverse (fractures at right angles to the long axis of the bone). In contrast, an oblique fracture departs from the long axis of the bone at a <90°, subparallel angle, and can either be straight or curved in a helical pattern (as illustrated in Figure 1). Analytical consideration of the ways in which these planes are combined in archaeofaunas has been used previously in attempts to elucidate fracture patterns at the assemblage level (e.g. Sadek-Kooros, 1975; Shipman et al., 1981).

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<sup>1</sup> Limb bones as defined here include the ungulate humerus, radioulna, metacarpal, femur, tibia and metatarsal, even though the metacarpals and metatarsals are technically bones of the foot. However, we group the metapodials with actual limb bones because they are anatomically and functionally similar to limbs in most ungulates. Further, we make this decision to avoid the often-used but vague term 'long bone' that, in many systems, includes such nonrelevant elements as proximal phalanges (see also Pickering et al., 2003).



**Figure 1.** Sketch of a fractured bovid tibia and its detached shaft fragment indicated in black. Longitudinal (L), transverse (T) and oblique (O) fracture planes are illustrated on the fragment edges. Note that a curved (helical) obliquely oriented fracture is illustrated, but that such fractures can also be straight.

Surprisingly, in the fallout of all this abundant and important research was a sobering perception that specific fracture types within these (and other) systems are highly subject to equifinality on at least one important level (e.g. Dart, 1957; Zierhut, 1967; Sadek-Kooros, 1972, 1975; Noe-Nygaard, 1977; Bonnichsen, 1979; Shipman & Phillips, 1976, 1981; Haynes, 1980, 1983, 1988; Myers et al., 1980; Binford, 1981; Lyman, 1989, 1994; Johnson, 1985a; Badam et al., 1986; Gibert et al., 1992, 1993; Charles, 1998; Marean et al., 2000). For example, although Villa & Mahieu's (1991) system of fracture angle analysis does reliably inform about the condition of bones when originally fractured (i.e. whether they were green or dry), it is still unable alone to inform about the agent(s) of those fracturing events. Because of this ambiguity in linking fracture form with specific taphonomic agents (e.g. hominids versus carnivores) and effectors (e.g. hammerstones versus teeth), fracture pattern data are still largely under-utilised by zooarchaeologists interested in reconstructing early hominid behaviour.

Fortunately, however, Capaldo & Blumenschine's (1994) seminal study demonstrated the merit of a refined consideration of fracture angles for reliably distinguishing breakage caused by the dynamic impact of a hominid-wielded hammerstone from that caused by the static loading of carnivore teeth. Alcántara García et al. (in press) have expanded usefully on this earlier research by Capaldo & Blumenschine (1994). Here we explain briefly the system introduced by Alcántara

García et al. (in press), summarise its experimental results, and then apply them to the ungulate limb bone component of the c. 1.0 million year old (Ma) archaeofauna from Swartkrans Member 3. This exercise illustrates the utility of this novel analytical method by providing new information about the carcass foraging behaviour of early hominid and carnivore bone accumulators at Swartkrans.

## **Materials and methods**

### The fossil sample and general methodology

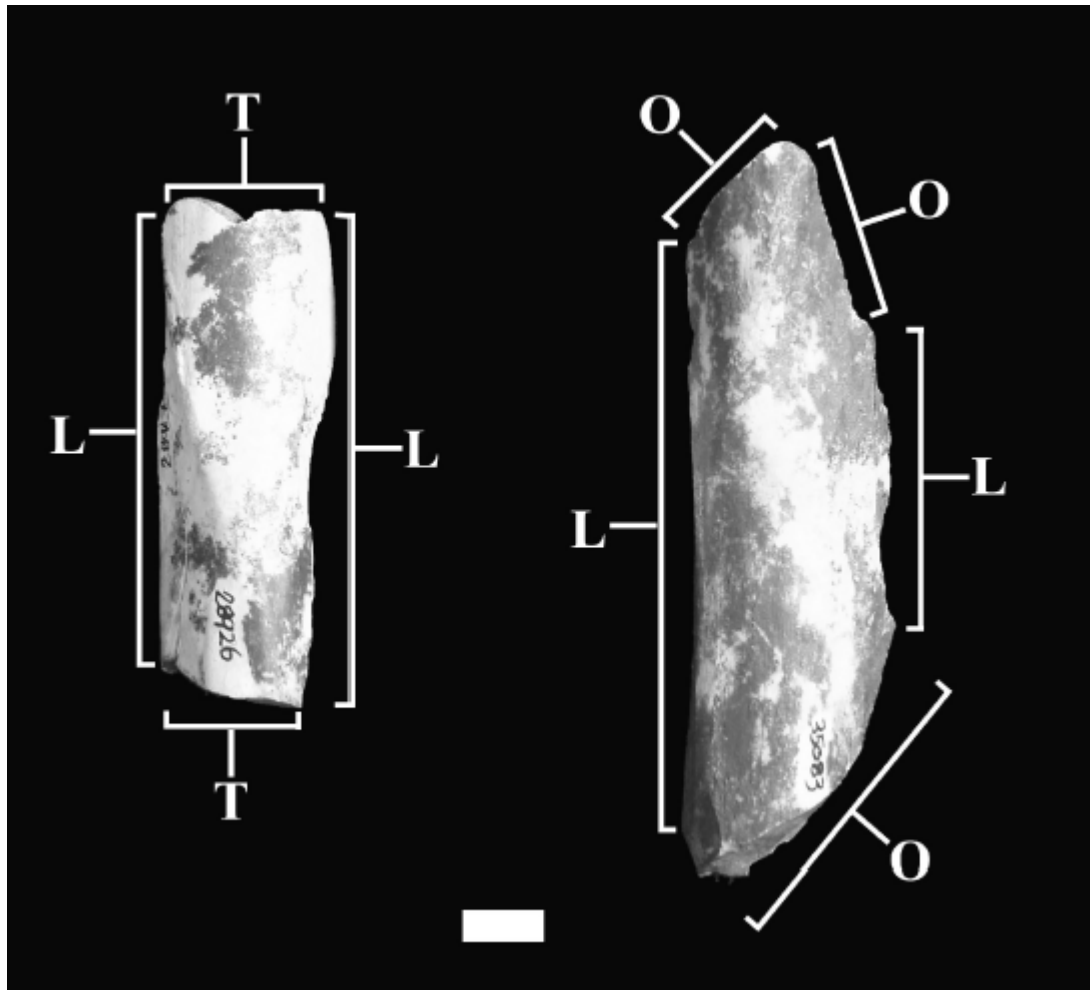
The Swartkrans Member 3 faunal assemblage (excavated 1979–1986) was analysed originally by Brain (1993a; Brain et al., 1988), Watson (1993) and Newman (1993). Member 3 is estimated to be c. 1.0 Ma (Brain, 1993b) and preserves fairly abundant remains of *Australopithecus robustus* in addition to fossils of many other mammalian taxa (Brain et al., 1988; Grine, 1988, 1989, 1993; Watson, 1993). In total, the Member 3 assemblage consists of 108,098 bone specimens (Watson, 1993). Of that total, we reanalysed 1466 specimens. This sample includes the complete ungulate limb bone shaft subassemblage  $\geq 5$  cm in maximum dimension, regardless of preserved bone surface modifications on those specimens. In addition, those limb bone shaft specimens  $< 5$  cm in maximum dimension with observed prehistoric bone surface damage were also included in our analysed sample. We collected data on numerous taphonomic attributes that are detailed elsewhere (Pickering et al., 2004a,b, 2005), but included for each specimen an assessment of skeletal element, bone portion, subaerial weathering stage, overall cortical condition, maximum dimensions and bone surface modifications (e.g. carnivore tooth marks, rodent gnaw marks, insect damage, ‘random’ linear striae and stone tool cutmarks and percussion marks). Following the recommendations of several experts (e.g. Bunn, 1982, 1991; Bunn & Kroll, 1986; Blumenschine & Selvaggio, 1988, 1991; Blumenschine, 1995; Blumenschine et al., 1996), bone surfaces were examined with the aid of a strong low-incidence light and at least 10x magnification. Attribution of bone surface damage was corroborated in a sample of specimens with scanning electron microscopy.

### Application of new system of bone fracture analysis

Using the system of Alcántara García et al. (in press), we also collected data on the condition of all pre-fossilisation, green fracture planes in the Swartkrans subassemblage of limb bone shaft specimens. A fracture plane is considered green if it possesses a smooth release surface and its measured angle is  $< 85^\circ$  or  $> 95^\circ$  (see discussion below, and that of Villa & Mahieu, 1991). Following these criteria, 903 individual fracture planes on 582 specimens from the Swartkrans Member 3 limb bone shaft subassemblage were used in this analysis. Because the system of Alcántara García et al. (in press) is new to zooarchaeology we outline it here, as well as presenting a summary of their pertinent experimental results (Table 1).

We first classified each green fracture plane as longitudinal, transverse or oblique. As Bunn (1982, 1989) has observed and commented, it is sometimes difficult to define boundaries between the end of one fracture plane and the beginning of another on a single bone specimen. Biddick & Tomenchuck (1975) and Davis (1985) have proposed analytical systems that might circumvent the problem highlighted by Bunn, but these systems are cumbersome and extremely

time-consuming (see discussions in Villa & Mahieu, 1991; Outram, 2001). Some of the limb bone shaft specimens in the Swartkrans Member 3 sample could be described as ovate or possess some other ‘irregular’ form. However, after our extensive experience with the assemblage, we are comfortable stating that the majority of specimens are less ambiguously classified. On this latter type of specimen, inter-plane boundaries were fairly straightforward to set, and we found a high degree of agreement among our research group for assigning those boundaries (Figure 2). If there was no agreement, then the specimen was not included in our sample. Next, we used a goniometer to measure the angle of each accepted fracture plane at the midpoint of the plane (see also Capaldo & Blumenschine, 1994). Midpoint measurements were the chosen standard because the fracture angle of a plane often varies along its full length. Each fracture plane was measured at least twice and measurements were recorded to the nearest whole degree.



**Figure 2.** Limb bone shaft specimens from Swartkrans Member 3 illustrating the boundaries of individual green fracture planes along each fossil. Abbreviations: L=longitudinal; T=transverse; O=oblique. Scale = 1 cm.

**Table 1.** Fracture attribute data for green broken limb bone shaft specimens of modern sheep and COWS

Fracture plane	Fracture source and angle							
	Sheep				Cow			
	Dynamic <90°	Dynamic >90°	Static <90°	Static >90°	Dynamic <90°	Dynamic >90°	Static <90°	Static >90°
<i>Longitudinal</i>								
Mean	74.33	107	88.1	104.7	71.5	116.3	79.7	103.8
S.D.	21.4	9.51	3.68	5.1	20.58	19.24	3.68	7.9
95% C.I.	62.5–86.5	103–112	85.7–91.8	100.4–109	63.1–79.8	108.8–124.6	74.1–85.3	98.8–108.8
<i>n</i>	15	22	9	7	26	24	9	12
Range	30–90	93–134	82–90	94–115	13–90	91–150	74–90	91–120
<i>Transverse</i>								
Mean	63.1	111.8	87.8	97	59.6	121.5		103.5
S.D.	14.15	12.65	3.4	5.8	18.13	47.2		7.9
95% C.I.	49.4–76.6	106.1–117.4	83.8–91.8	91.4–103.6	45.9–73.2	76.3–166.6		93.5–113.5
<i>n</i>	7	5	5	5	17	7		12
Range	20–90	94–124	85–90	91–104	40–89	90–169		91–120
<i>Oblique</i>								
Mean	72.2	115	80.4	105.2	59.2	126.5	82.3	107.4
S.D.	20.94	7.5	14.7	12.3	18.08	15.96	5.07	8.83
95% C.I.	63.9–80.4	111–119	76.6–84.4	100.2–110.2	55.8–62.6	121.2–131.8	76.6–88.9	101.4–113.4
<i>n</i>	27	27	6	8	48	38	9	12
Range	30–90	103–130	71–90	95–133	16–86	95–165	76–89	95–125

Notes: Alcántara García et al. (inpress) should be consulted for full experimental details. In summary, 124 shaft specimens were created by hammerstone percussion (dynamic loading) from a starting total of 14 whole limb bones (three humeri, one radius, five femora and five tibiae). Bones were struck with the unmodified surfaces of four hammerstones, which ranged in diameter from 8–14 cm and in weight from 556–1164 gm. In each case, a defleshed bone still retaining its periosteum was rested on an anvil positioned directly below the intended point of impact (cf. Bunn,1989).However, because novice (student) bone-breakers were used in the study, impact points varied between bones with respect to the aspect (medial, lateral, ventral or dorsal) on which force was directed and along the length of each. Next, 48 shaft specimens were created by pressure (static loading) from a starting total of 11 whole limb bones (two humeri, one radius, five femora and three tibiae). Most of these shaft fragments resulted from the chewing activities of a large domestic dog and spotted hyenas on nine of the limb bones. However, in order to increase sample size, another two bones were broken by humans using pliers; this effectively simulated the static loading of carnivore chewing (see also Capaldo & Blumenschine,1994).Fractures imparted by dynamic and static loading on metapodials were not separable into exclusive groups (probably due to the greater thickness of metapodials relative to upper and intermediate limb bones), and thus were not considered systematically in the study of Alcántara García et al. (in press).Data are summarised for each fracture plane (longitudinal, transverse and oblique) and by animal body size. Using the well-known classification scheme of Brain (1981), sheep fall into size classes 1 and 2 (small animals), while cows are size class 3 (large animals). Data include means, standard deviations (S.D.) and 95% confidence intervals (C.I.) using a *t* distribution in which *t* 0.025 is the critical value with *n*=1 degrees of freedom.

Based on the combined analysis of preserved fracture planes and fracture angles (as defined by Villa & Mahieu, 1991; see above), Alcántara García et al. (in press) documented statistically significant differences between a sample of 124 green sheep and cow limb bone specimens (263 fracture planes) broken by modern human subjects using stone hammers (percussion or dynamic impact) and 48 (94 fracture planes) fractured by the chewing of a large domestic dog and wild spotted hyenas (pressure or static loading). The legend to Table 1 contains pertinent information

on the experimental protocol of Alcántara García et al. (in press), but readers are encouraged to consult the original publication for more details.

In general, a green bone will fracture, relative to its long axis, along oblique and/or longitudinal planes, and will preserve fracture angles that vary but are usually  $<85^\circ$  or  $>95^\circ$ . This is in contrast to a dry broken bone, which will typically break along transverse and/or longitudinal planes at a  $\sim 90^\circ$  angle and with an irregular release surface (see also Villa & Mahieu, 1991). More specifically, within Alcántara García et al.'s (in press) sample of green bone broken by human hammering and carnivore chewing, there is notable overlap in the range of angles imparted by each activity along longitudinal fracture planes. An exception is the occurrence of acute angles on fragments from the larger cow bones (size class 3; for size class definitions, see Brain, 1981). In addition, there is also much overlap in the angles of transverse fractures imparted by humans and carnivores, especially on bone specimens from large animals and with angles  $>90^\circ$ .

In contrast to longitudinal and transverse fractures, there is much less overlap in the angles of oblique fractures imparted by humans and carnivores. Fortunately, oblique fractures are also the most common fracture type imparted by both agents of fracture. Finally, it appears that transverse fractures are less informative than longitudinal and oblique fractures for two reasons: they occur much less often than do longitudinal and oblique fractures, and this smaller sample size means that the range of variation of angles along transverse planes is wider and with more overlap.

The results of Alcántara García et al. (in press) can be summarised thus. Carnivore-imparted fractures on green bone are usually between  $80^\circ$ – $110^\circ$  (but generally not in the  $85^\circ$ – $95^\circ$  range, characteristic of dry breaks), while human-imparted fractures (especially those along oblique planes) are usually more acute ( $<80^\circ$ ) or more obtuse ( $>110^\circ$ ). These differences are statistically significant, and most apparent on longitudinal and especially oblique fracture planes. Except in cases with extreme angle values, fracture angles on transverse planes are generally ambiguous indicators of the agent of fracture.

## Results

Results of the Swartkrans Member 3 limb bone fracture analysis are summarised in Table 2. Comparisons of mean values and 95% confidence intervals between Member 3 and the experimental sample of Alcántara García et al. (in press) are summarised in Figure 3. For acute angle fractures on longitudinal planes, the Swartkrans small animal mean is identical to that of the modern sample created by human percussion, while the Swartkrans large animal mean falls comfortably within the ranges of and close to the means of both modern samples. Obtuse angle fractures on longitudinal planes in both the small and large animal Swartkrans samples have means identical to that of the modern carnivore-derived sample, but within the range of both modern samples. The majority of fracture angle means on transverse planes in the Swartkrans sample are closest to those in the modern human-derived sample. The means of both acute and obtuse fracture angles on oblique planes in the Swartkrans small animal sample are within the ranges of the human- and carnivore-derived samples. The same can be said of the obtuse angle

mean for the Swartkrans large animal sample, while the acute angle mean in that sample is outside the range of the modern carnivore-derived sample.

**Table 2.** Fracture attribute data for green broken limb bone shaft specimens in the Swartkrans Member 3 archaeofauna, by animal body size

Fracture plane	Small		Large	
	<90°	>90°	<90°	>90°
<i>Longitudinal</i>				
Mean	74.2	104.1	75.9	104.9
S.D.	14.9	9.74	14.9	13.5
95% C.I.	72.1–76.4	101.9–106.3	72.9–78.9	101.3–108.6
<i>n</i>	231	99	122	63
<i>Transverse</i>				
Mean	673	109	72	119.3
S.D.	18	18.9	21	8
95% C.I.	53.3–81.3	86–132	53–90	99.3–139.3
<i>n</i>	9	5	7	3
<i>Oblique</i>				
Mean	71.8	108.5	67.4	110.5
S.D.	15.07	14.27	18	15.87
95% C.I.	69.1–74.5	105.5–111.5	63.3–71.5	106.3–114.9
<i>n</i>	119	82	94	69

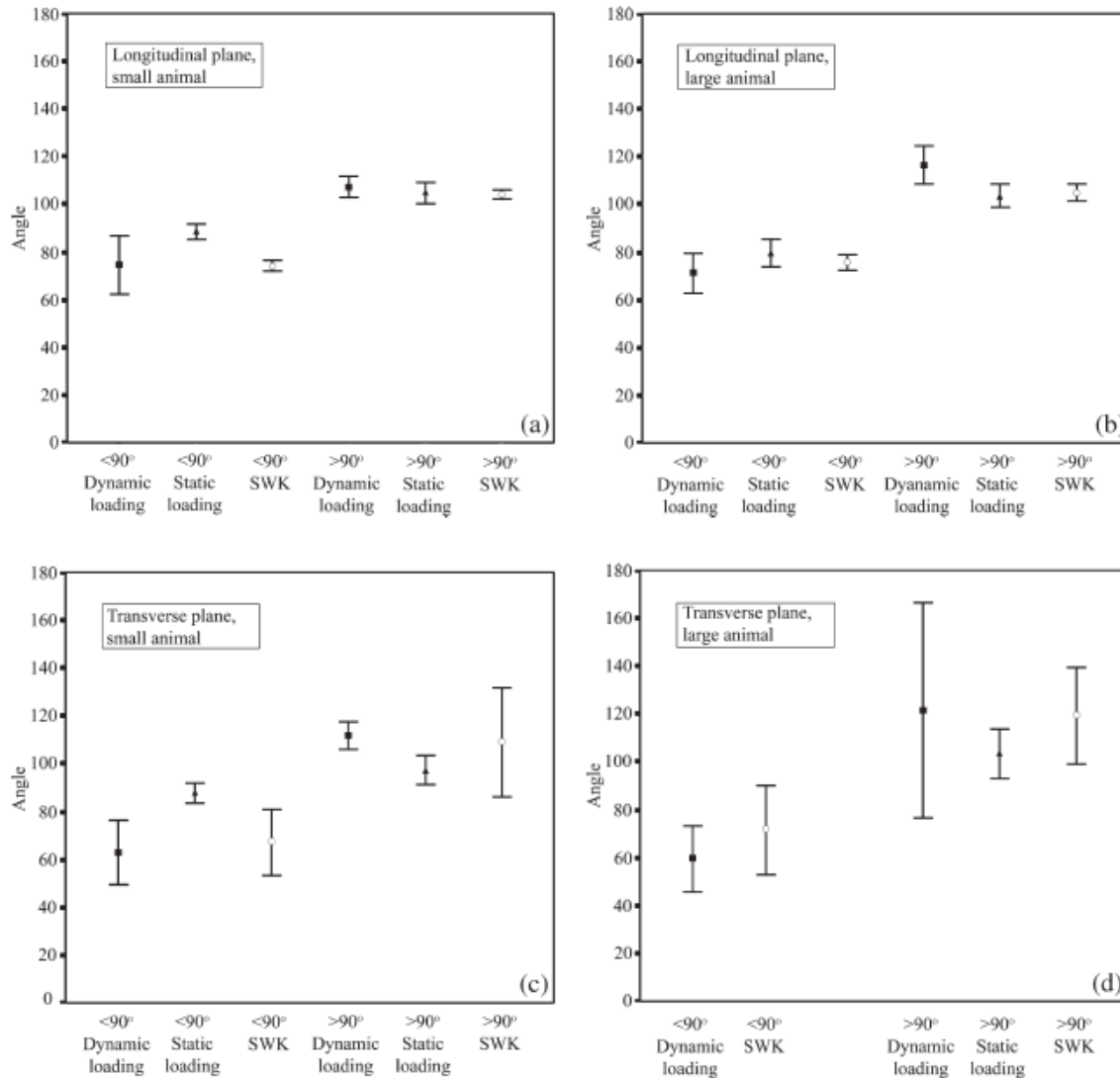
Notes: Data are summarised for each fracture plane (longitudinal, transverse and oblique) and by animal body size. Using the well-known classification scheme of Brain (1981), small animals fall into size classes 1 and 2, while large animals are size class 3 and larger. Data include means, standard deviations (S.D.) and 95% confidence intervals (C.I.) using a t distribution in which  $t_{0.025}$  is the critical value with  $n/41$  degrees of freedom.

Based on these comparisons, it appears that both hominids and carnivores acted as agents of bone fracture during the formation of the Swartkrans Member 3 faunal assemblage. This suggestion is strengthened considerably by drawing on the complementary classes of taphonomic data of hammerstone percussion marks and carnivore tooth marks. Fractures on specimens that also bear hammerstone percussion marks, such as pits, striae and notches (e.g. Leroi-Gourhan & Brezillon, 1972; Bunn, 1982; Turner, 1983; Blumenschine & Selvaggio, 1988, 1991; Capaldo & Blumenschine, 1994), have fairly low mean values for acute angles (56.3°–76.6°) and fairly high mean values for obtuse angles (92.0°–125.2°) (Table 3). These values are indicative of hammerstone percussion with reference to the modern experimental sample (Table 1). This corroboration between percussion-imparted surface damage and angle creation implies fairly robust diagnostic value for the use of green break angles in identifying dynamic fracture events.

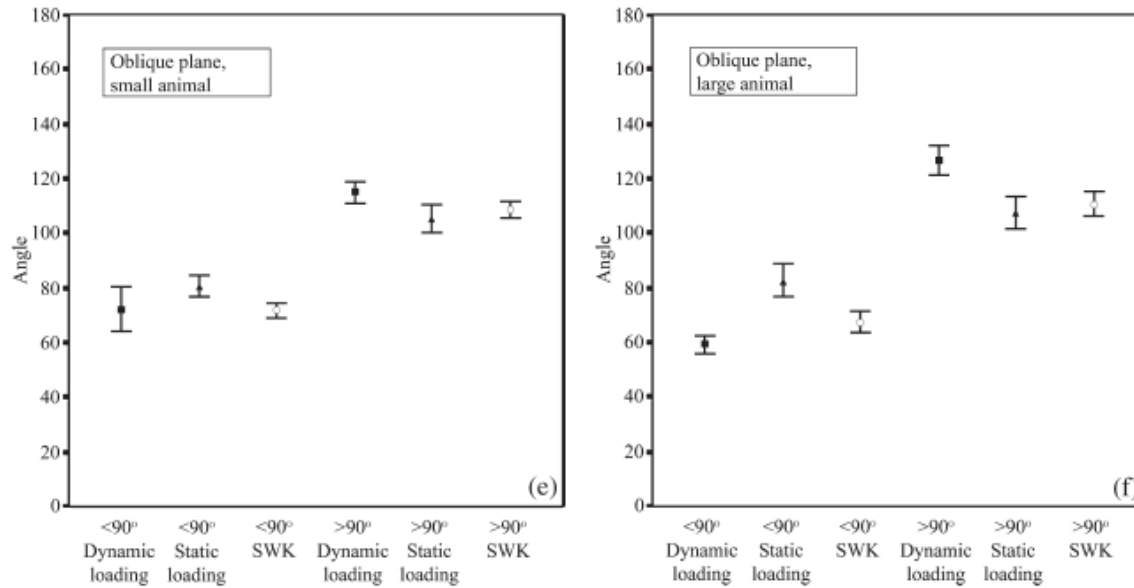
Conversely, examination of fracture angles on specimens that also bear tooth marks reveals values in the high range for acute angles (71.4°–80.8°) and in the low range for obtuse angles (106.8°–116.0°) (Table 3). These values match closely those observed in the experimental sample created by carnivores (Table 1). These observations are particularly important to zooarchaeologists attempting to reconstruct hominid involvement in the formation of an archaeofauna that was also impacted by carnivores. As Henry Bunn (personal communication, 2004) reminded us, carnivore tooth marks can sometimes occur on bone specimens first broken open by hammerstone percussion, indicating that carnivores were exploiting the most marginal residues of bone resources first consumed by hominids. The tight agreement between fracture



angle values in the Swartkrans tooth-marked sample and those values in the modern carnivore-created sample, implies this was an unlikely scenario in the formation of the Member 3 limb bone subassemblage. In other words, based on fracture angle data, we posit minimal hominid–carnivore interdependence in the creation of that assemblage. This result supports our previous conclusion based on the very low co-occurrence of hominid butchery damage and carnivore tooth marks on individual fossil specimens in Swartkrans Member 3 (Egeland et al., 2004; Pickering et al., 2005).



**Figure 3.** Comparison of mean percentages and 95% confidence intervals for fracture angles in Alcántara García et al.’s (in press) modern hammerstone percussion (dynamic loading) and carnivore chewing (static loading) samples and Swartkrans (SWK) for: longitudinal planes on small (a) and large (b) animal specimens; transverse planes on small (c) and large (d) animal specimens (note: there is no modern static loading sample with acute angles available for comparison); and oblique planes on small (e) and large (f) animal specimens.



**Figure 3.** Continued.

**Table 3.**

Fracture plane	Percussion marked		Tooth marked	
	<90°	>90°	<90°	>90°
<i>Longitudinal</i>				
Mean	76.6	104.7	80.8	106.8
S.D.	12.5	8.6	8.7	12.07
95% C.I.	70.4–82.8	95.7–113.3	78–83.6	103.5–110.2
<i>n</i>	20	7	45	63
<i>Transverse</i>				
Mean	56.3	92.0	75.3	116.0
S.D.	17.1	0	15.2	16
95% C.I.	16.3–99.3	0	63.3–87.3	96–136
<i>n</i>	3	1	8	5
<i>Oblique</i>				
Mean	64.6	125.2	71.4	113.3
S.D.	12.86	14.5	17.8	16.0
95% C.I.	57.5–70.7	102.7–147.7	66.4–76.4	109.3–117.3
<i>n</i>	16	4	45	78

Notes: Data are summarised for each fracture plane (longitudinal, transverse and oblique) and by bone surface modification type, percussion marks and tooth marks. Data include means, standard deviations (S.D.) and 95% confidence intervals (C.I.) using a t distribution in which  $t_{0.025}$  is the critical value with  $n-1$  degrees of freedom.

## Discussion and conclusions

### Implications for understanding early hominid behaviour at Swartkrans

Most of the well-known early hominid cave sites in South Africa have faunal assemblages that preserve scant zooarchaeological evidence of hominid involvement in their accumulation (e.g. Brain, 1981; Pickering, 1999, 2002). An exception is the presence of several cutmarked bone specimens and many other burned pieces from Swartkrans Member 3 documented by Brain

(1993a: 263) and leading him to suggest ‘that hominids were using stone tools for the removal of meat from bones while sitting round their camp-fires’. Pickering et al.’s (2004a,b, 2005) reanalysis of the Member 3 ungulate limb bone shaft subassemblage supplements Brain’s original observations by expanding the cutmark count to 60 total specimens preserving such damage; and we have reason to suspect that our continued work on the remainder of the assemblage will result in the identification of even more cutmarks on specimens from other body regions.

In addition to the new cutmarked specimens, we also documented 50 specimens with hammerstone percussion damage (3.5% of total analysed specimens)<sup>2</sup> and 532 with carnivore tooth damage (36.3% of total analysed specimens); a very few specimens preserve various combinations of cut, percussion and tooth damage (Pickering et al., 2004a,b, 2005; Egeland et al., 2004). Blumenschine & Selvaggio (1988) demonstrated that ~30% of all specimens in experimental limb bone assemblages broken by human percussion bear at least one percussion mark. In order to compare the Swartkrans data to that experimental standard, we adjusted the fossil data to compensate for several factors common in fossil bone assemblages but non-existent in the modern comparative sample (Pickering et al., 2005). One of these factors most relevant to the current discussion is the prevalence of diagenetic fracture in the Member 3 archaeofauna and its complete absence in modern assemblages. Thus, we sampled randomly several hundred specimens across various standardised size-range categories, allowing assessment of the magnitude of diagenetic breakage in the Swartkrans assemblage as a whole. In summary, when the Swartkrans data are adjusted to make them more comparable to actualistic samples created by Blumenschine & Selvaggio (1988) and others, percussion-damaged specimens drop to 1.1% (n=28) of the new total number of specimens of 2641, and carnivore tooth marked specimens rise to 5.1% (n=135) of the total (Pickering et al., 2005).

Thus, whether considering raw or adjusted values, the very low proportion of percussion-marked specimens in the Swartkrans sample, contrasted with the higher incidence of carnivore-damaged specimens, indicates that carnivores were more active agents of bone fracture than were hominids during the accumulation of the assemblage. In addition, we also recognise that some of the Swartkrans fractures that seemingly indicate carnivore activity may have been created by other types of static loading on green bones (such as sediment compaction as the assemblage was forming on the cave floor). However, neither alternative (i.e. static loading by carnivores or sediment pressure) changes an inference of minimal bone breakage by hominids employing dynamic hammerstone percussion.

That said, it is still important to note that the new data presented here combined with those published elsewhere (e.g. Pickering et al., 2004a,b, 2005; Egeland et al., 2004) hold the potential to alter dramatically our views of early hominid carcass foraging in southern Africa—which until this point had been based on a total of only 15 cutmarked and chopmarked bone specimens from Swartkrans and Sterkfontein (Brain, 1993a; Pickering, 1999), and an unspecified but very low

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<sup>2</sup> This total includes specimens with percussion pits, striae and/or notches, and is exclusive of an additional 53 impact flake specimens (Pickering et al., 2004b, 2005). With regard to those impact flakes, it is interesting to note that while too small to measure, almost all of them preserve obtuse fracture angles. This means that the corresponding bone specimens from which they were detached will preserve acute angles along their release surfaces.

number of hammerstone-percussed specimens from Swartkrans (Bishop & Blumenschine, 1994).<sup>3</sup> In sum, our analyses have increased by nearly 150 new specimens the total number of hominid-butchered bones documented from all known early Pleistocene South African archaeofaunas combined, and moves Swartkrans Member 3 behind only FLK 22 Zinjanthropus (Olduvai Gorge, Tanzania) for the total number of hominid-modified bones from the whole of Africa (Pickering et al., 2005). In addition, the current analysis of fracture angle patterns corroborates our previous suggestion that the hominid- and carnivore-derived portions of Swartkrans Member 3 were contributed mostly independently of one another (Egeland et al., 2004; Pickering et al., 2005). This means that the assemblage might offer palaeoanthropologists the unique opportunity to examine assemblage-formation behaviour by hominids in relative isolation from ‘taphonomic overprints’ more common in faunas that formed under higher degrees of interdependence between hominids and carnivores.

### Broader analytical implications

As discussed above, bone surface damage data in Swartkrans Member 3 corroborate the conclusions about site formation drawn independently from data on limb bone fracture patterns. However, few other South African cave sites that yield archaeological remains also have fossils with cortices as well-preserved as those in Swartkrans Member 3 (e.g. Sterkfontein Member 5; Pickering, 1999). This limits the utility of bone surface modification analyses in these other assemblages; and the same situation characterises many other Plio-Pleistocene faunas of potential zooarchaeological importance. This might be initially disheartening since bone surface modifications are currently one of the most powerful sources of data in constructing inferences of early hominid foraging behaviour. However, this also creates the impetus for important work to establish other types of datasets and criteria that can accurately differentiate the relative taphonomic impact of carnivores and hominids in an archaeofauna. The archaeological results presented here for Swartkrans Member 3 supplement the original experimental findings of Alcántara García et al. (in press) on fracture patterns. They indicate further that, while not ideal, the system can be used in isolation to infer the relative contribution of early hominid behaviour in poorly preserved faunal assemblages.

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<sup>3</sup> Brain & Sillen (1988; Brain, 1993c) have also reported the presence of 270 burned bone specimens from Swartkrans Member 3, which may have resulted from the fire-using activities of early hominids

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