

Hominin–carnivore interactions during the Chinese Early Paleolithic: Taphonomic perspectives from Xujiayao

Christopher J. Norton^{a,b,*}, Xing Gao^a

^a Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, 142 Xizhimenwai Street, Beijing 100044, China

^b Department of Anthropology, University of Hawai'i at Manoa, 2424 Maile Way, Saunders Hall 346, Honolulu, HI 96822, USA

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Abstract

The ability of archaic *Homo sapiens* to survive in more northerly latitudes was contingent on securing a regular source of animal fat and protein. We present a taphonomic study that examines how successful these hominins were at acquiring these food sources during the latter part of the Early Paleolithic in Northeast Asia. This study focuses on the long bone midshaft surface modifications observed on the faunal remains from Xujiayao, a middle-late Pleistocene open-air site located at 40° latitude in the western Nihewan Basin, northern China. The faunal assemblage is dominated by equid remains. Analysis of the percussion, tooth, and cut mark frequencies on the long bone midshafts demonstrates that the Xujiayao hominins had primary access to high utility (meat-bearing and marrow-rich) long bones. Investigation of the dual-patterned (tooth-marked and butchery-marked) bone fragments suggests that hominins were under little pressure from competing carnivores to abandon their kills. The lack of significant differences between the size of fragments with only percussion-marks and those with only tooth-marks supports these findings. Fragmentation ratios indicate that forelimbs were more intensively processed than hind limbs. Based on the water rounding and abrasion data, the Xujiayao assemblage is likely of autochthonous origin. Since the age of Xujiayao is still in question, we can only conclude that archaic *Homo sapiens* were successful predators of large game in Northeast Asia some time during the latter part of the Early Paleolithic. © 2008 Elsevier Ltd. All rights reserved.

Keywords: China; Archaic *Homo sapiens*; Hunting; Bone surface modifications; Long bone midshafts

Introduction

The ability of archaic *Homo sapiens* to survive successfully in northern latitudinal climates depended on an array of biological and behavioral adaptations. The capacity to inhabit these environments in the Early to Middle Paleolithic is strongly correlated with early evidence of modern human behavior (Henshilwood and Marean, 2003).¹ One of the most

important adaptive traits would have been the ability to consistently procure sources of animal fat and protein (Aiello and Wheeler, 1995; McBrearty and Brooks, 2000). In this study, we address the issue of when, in the archaeological record, we begin to see evidence for the regular acquisition of large game resources by hominins in Pleistocene Northeast Asia. Currently, evidence of early effective hominin predation is found in Africa and western Eurasia during the middle-late Pleistocene transition (McBrearty and Brooks, 2000; Henshilwood and Marean, 2003). The middle-late Pleistocene transition is correlated with the European and Levantine Middle Paleolithic, the Middle Stone Age in Africa (Klein, 1999; Phillipson, 2005), and the Early Paleolithic in East Asia (Gao, 1999; Norton, 2000a; Gao and Norton, 2002; Norton et al., 2006, in press).

A number of taphonomic studies have investigated the nature of hominin–carnivore interactions during the late

* Corresponding author.

E-mail addresses: k_s_g@hotmail.com; cnorton@hawaii.edu (C.J. Norton), gaoxing@ivpp.ac.cn (X. Gao).

¹ Even though the Dmanisi *Homo erectus* site is also situated at more northerly latitudes (Gabunia et al., 2000), how successful these early hominins were at surviving in these northerly latitudinal regions of the Old World is still not currently understood (Tappen et al., 2002).

middle-late Pleistocene transition (e.g., Binford, 1984, 1985; Chase, 1986, 1989; Hoffecker et al., 1991; Grayson and Delpech, 1994, 2003; Stiner, 1994, 2002; Klein and Cruz-Uribe, 1996, 2000; Marean, 1998; Marean and Kim, 1998; Milo, 1998; Bartram and Marean, 1999; Marean and Assefa, 1999; Marean et al., 2000; Munson and Marean, 2003; Assefa, 2006). Interpretations of these zooarchaeological data have varied, with some researchers arguing that early modern humans and Neandertals regularly scavenged the remains of carcasses procured by other carnivores (e.g., Binford, 1984, 1985; Stiner, 1994, 2002) and others proposing that these hominins had early access to large game (e.g., Marean and Kim, 1998; Bartram and Marean, 1999; Marean et al., 2000; Assefa, 2006).

For the most part, the differences in these interpretations reflect the integrity of the faunal assemblages and the different methodologies employed by the researchers. In many cases that have been interpreted as evidence of hominin scavenging, it has been shown either that the composition of the faunal assemblage was biased by the preferential retention of certain types of bone specimens or that the abundant long bone mid-shaft fragments were not incorporated into the element counts (Marean, 1998; Marean and Kim, 1998; Marean and Assefa, 1999; Marean et al., 2000; Pickering et al., 2003; Norton et al., 2007a).

Most of these studies have focused on sites from Africa and Europe. In one of the few studies of middle Pleistocene materials from East Asia, Binford and Stone (1986) analyzed a small subset of the faunal remains from Zhoukoudian Locality 1 (c. 800–400 ka: Shen et al., 2001; or c. 550–200 ka: Grun et al., 1997). The problems with Binford and Stone's taphonomic study aside (which include neglecting nearly all the postcranial faunal remains; see most of the comments in

their paper, Bunn and Kroll, 1987, and Dong, 1996), Zhoukoudian Locality 1 is only associated with *Homo erectus* fossils. In this study, we present a taphonomic analysis of Early Paleolithic faunal materials from East Asia associated with archaic *Homo sapiens* from the site of Xujiayao in the western Nihewan Basin, northern China.

Background of Xujiayao

Xujiayao (40°06'028"N; 113°58'414"E; c. 970 m above sea level) is an open-air site discovered in 1974 during field reconnaissance by members of the Institute of Vertebrate Paleontology and Paleoanthropology (IVPP), Chinese Academy of Sciences. The site is located on the west bank of the Liyi River and is named after the local village (Fig. 1). Xujiayao was excavated in 1976, 1977, and 1979 by the IVPP under the direction of Professor Lanpo Jia. Xujiayao is represented by two localities (74093 and 73113), with the majority of the artifactual and vertebrate paleontological materials recovered from Locality 74093 (Jia and Wei, 1976; Jia et al., 1979; Wu and Poirier, 1995). Sieving was not performed during the excavations. However, efforts were made to collect all of the lithics and faunal materials including the long bone shaft fragments, many of which were thought to be bone tools (Qi Wei, pers. comm.). The materials from Locality 74093 form the foundation of this study.

Xujiayao is comprised of fluviolacustrine deposits. The stratigraphic profile consists of a series of erosional surfaces intercalated with eight sandy clay and silty clay depositional layers (Fig. 2). The thickness of the deposits has been reported to have been between 15–20 m (Lovlie et al., 2001) or 26–28 m (Jia et al., 1979) with the majority of the paleoanthropological residues situated in stratigraphic level II [eight

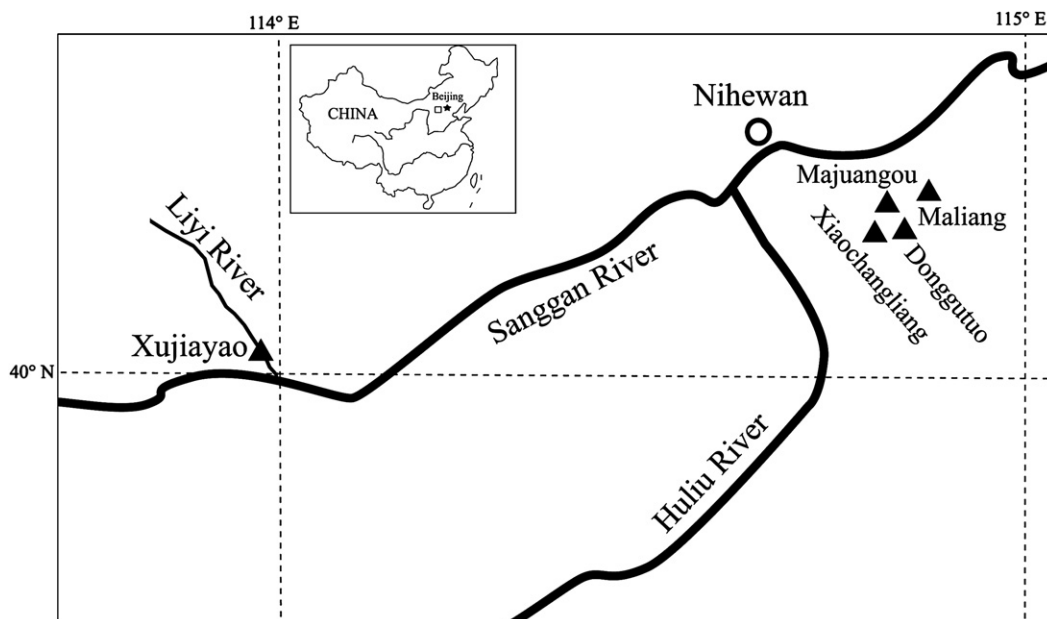


Fig. 1. Location of Xujiayao, western Nihewan Basin, China. Majuangou, Xiaochangliang, Donggutuo, and Maliang are other important early and middle Pleistocene sites from the eastern Nihewan Basin.

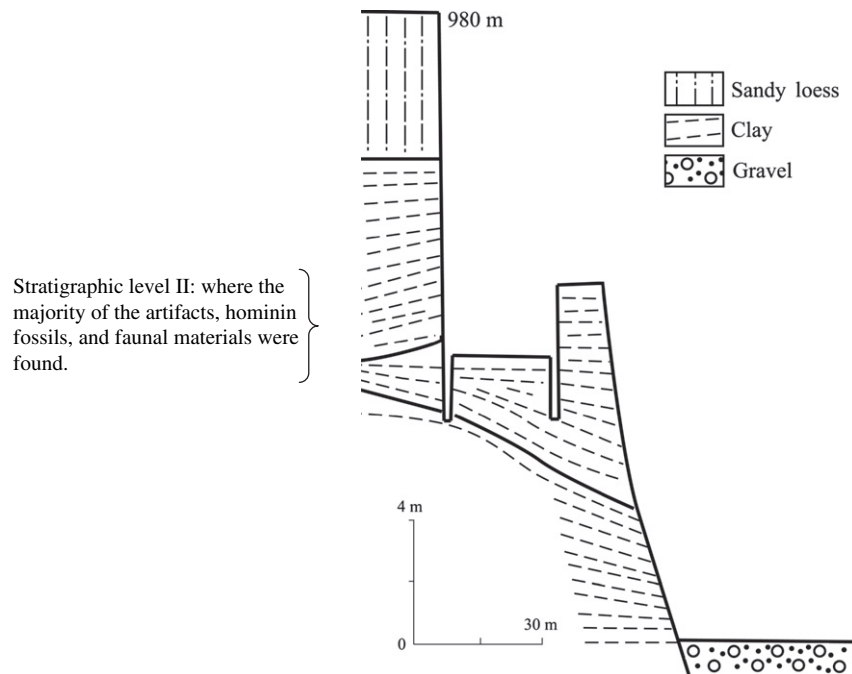


Fig. 2. Stratigraphy of Xujiayao site (after Jia et al., 1979). Even though eight separate stratigraphic layers were described (see Wu and Poirier, 1995), only five clear stratigraphic layers were drawn by Jia et al. (1979: their Fig. 2). In addition, Lovlie et al. (2001) note that the escarpments are 15–20 m high, though according to Wu and Poirier's (1995) reconstruction, the stratigraphic profile was 26–28 m. We use the original stratigraphic profile as drawn by Jia et al. (1979) and consider the first clay layer as the equivalent of their stratigraphic level II since it is 8–12 m below the topsoil.

to twelve meters below the present-day surface (Jia et al., 1979)].

A variety of chronometric ages for the Xujiayao deposits have been proposed (Table 1). Uranium-series dating on *Equus* (horse) teeth indicates an age bracket between 114–88 ka, and on *Coelodonta antiquitatis* (woolly rhinoceros) tooth enamel an age of 91 ka has been proposed (Chen et al., 1982). However, ^{14}C dating on bone materials suggests a much younger age of 16 ka for the deposits (Wu and Wang, 1985). A recent paleomagnetic reconstruction determined that the uppermost 15 m of deposit had a normal polarity magnetization (Brunhes Chron), with the underlying strata representing a reversed polarity zone (Lovlie et al., 2001). According to Lovlie et al. (2001), the underlying reversed polarity zone was too extensive to represent a brief excursion (e.g., Blake Episode), and most likely represented the Matuyama Chron. Assuming a uniform sedimentation rate, it was then proposed that the age of the deposits should be early Brunhes, which could indicate

that Xujiayao is coeval with Zhoukoudian Locality 1. To date, there is no clear consensus regarding the age of the Xujiayao deposits (Norton et al., in press). However, we propose that the age range is likely between the late middle Pleistocene and the early late Pleistocene based on the uranium series and magnetostratigraphic studies and the absence of Late Paleolithic technology [i.e., the blade and microblade technology that appears in China after 40 ka (Gao and Norton, 2002; Norton et al., in press)]. We consider the materials to have been deposited some time during the latter part of the Early Paleolithic. In collaboration with researchers from Peking University, we are currently applying optically stimulated luminescence to determine a more reliable age range for the site.

Xujiayao is best known for the presence of archaic *Homo sapiens* fossils (Wu and Poirier, 1995). Fragments from twelve parietals, one temporal, two occipitals, one juvenile maxilla, and one mandible have been identified, along with two

Table 1
Chronometric dates of Xujiayao deposits

Specimen #	Age	Material	Method	Reference
BKY 80001	99,000 ± 6000	Equid dentine	Uranium series	Chen et al., 1982; Wu and Wang, 1985
BKY 80002	88,000 ± 5000	Equid dentine	Uranium series	Chen et al., 1982; Wu and Wang, 1985
BKY 80003	102,000 ± 6000	Equid dentine	Uranium series	Chen et al., 1982; Wu and Wang, 1985
BKY 80012	114,000 ± 17,000	Equid dentine	Uranium series	Chen et al., 1982; Wu and Wang, 1985
BKY 81012	94,000 ± 7000	Equid dentine	Uranium series	Chen et al., 1982; Wu and Wang, 1985
BKY 81014	91,000 ± 9000	Rhinoceros enamel	Uranium series	Chen et al., 1982; Wu and Wang, 1985
ZK-670-0(1)	16,920 ± 2000	Rhinoceros bone	^{14}C	Wu and Wang, 1985
ZK-670-0(2)	16,450 ± 2000	Rhinoceros bone	^{14}C	Wu and Wang, 1985
Not applicable	Early Brunhes	Not applicable	Magnetostratigraphy	Lovlie et al., 2001

isolated left upper molars and one lower molar. These hominin fossils are described in detail elsewhere (see Jia et al., 1979; Wu, 1980; Wu and Poirier, 1995), but would benefit from further analyses, which are beyond the scope of this paper. More than 13,000 Early Paleolithic core and flake tools have been reported, including polyhedral cores, scrapers, points, bola balls, and burins; 65% of the lithics are produced using locally available vein quartz (Jia et al., 1979). A detailed study of the Xujiayao cultural materials remains to be conducted.

Twenty-one taxa are represented in the faunal assemblage from Xujiayao (Table 2). The assemblage is dominated by *Equus przewalskii* (Przewalskii's wild horse) and *E. hemionus* (kulan) remains. *Coelodonta* and small artiodactyls [*Spirocerus* (antelope), *Procapra* (gazelle), and *Gazella* (gazelle)] are the next most common taxa. The taxonomic representation is indicative of a cool, temperate, open grassland environment, although a small percentage of forest-dwelling taxa [e.g., *Cervus* (deer) and *Sus* (pig)] are also present in the assemblage.

Materials and methods

The Xujiayao faunal assemblage, comprising roughly 5000 specimens, is stored in the IVPP. The bone and taphonomic identifications followed procedures described in our previous studies (e.g., Norton et al., 1999, 2007b; Norton, 2000b). All statistical analyses were run in SPSS 11.5, with results considered significant if $p \leq 0.05$.

Only the identifiable long bone specimens that could be assigned to skeletal element and at least taxonomic order/family, were included in this study [number of identified specimens

(NISP) = 990]. We used modern comparative materials stored in the IVPP for the taxonomic and element identifications. The determination of minimum number of elements (MNE) was based on the highest counts of anatomical landmarks for each element (Table 3). Identifications to taxa were to the order, family, and/or genus level. Among the perissodactyls, it was easy to distinguish between equids and *Coelodonta* based on size and texture of the bone, with the latter having generally thicker, flakier, and more trabecular bone. In the case of the artiodactyls, it was more difficult to make the genus-/species-level identifications. Ten different species were originally identified in the assemblage (Jia et al., 1979; Table 2). Cervids and *Sus* (typically forest-dwelling taxa), though relatively easy to distinguish from the other artiodactyls identified at Xujiayao, were quite rare in the long bone assemblage. Accordingly, the mammal specimens were identified to order, and the artiodactyls were then grouped into general size categories which we modified from those created by Brain (1981) and Bunn (1982) for South and East Africa, respectively, in order to make them more applicable to the East Asian vertebrate paleontological record. The categories are: Size 1 representing *Gazella*, *Procapra*, and *Spirocerus*; Size 2 representing *Cervus nippon*; Size 3 representing *Cervus elaphus*; and Size 4 representing *Bos primigenius* (Table 4). For the perissodactyls, *Equus hemionus* and *E. przewalskii* were considered Size 3. *Coelodonta* and *Palaeoloxodon* were grouped into their own Size 5 category, representing taxa >1500 kg. The general size categories are based on male adults from each taxon size group and are specific to the Xujiayao taphonomic study. However, these taxon size categories are clearly applicable to most faunal assemblages in East Asia. Due to small sample sizes, we collapsed the artiodactyls into two broader size categories (1/2 and 3/4) for this analysis.

Cut mark, percussion mark, and tooth mark data were collected, along with evidence for burning, trampling, root etching, rodent gnawing, and water smoothing, following standard taphonomic procedures (e.g., Binford, 1981; Brain, 1981; Gifford, 1981; Shipman, 1981; Haynes, 1983; Shipman and Rose, 1983; Johnson, 1985; Behrensmeier et al., 1986; Blumenschine and Selvaggio, 1988, 1991; Capaldo and Blumenschine, 1994; Lyman, 1994; Fisher, 1995; Pickering and Egeland, 2006). Each specimen was held under bright, high incident light and carefully rotated at different angles to allow reflection off the cortical bone surface. This facilitated the identification of possible marks on the bones, particularly the presence of microstriations that emit from the pits of percussion marks (Blumenschine, 1995; Blumenschine et al., 1996). Possible marks were then studied under the light with a 16X hand lens.

Our analysis focused on bone surface modifications on the long bone midshafts, which are argued to provide the most informative data to address issues related to the nature of hominin–carnivore interactions (Blumenschine, 1988, 1995; Marean, 1998; Marean and Kim, 1998; Bartram and Marean, 1999; Marean et al., 2000; Pickering et al., 2003; Blumenschine and Pobiner, 2006). Based on the long bone counts, the minimum number of individuals (MNI) is 40 for horses,

Table 2
Taxa present in the Xujiayao assemblage (after Jia et al., 1979)

Order	Genus/species	Common name
Primates	Archaic <i>Homo sapiens</i>	Archaic <i>Homo sapiens</i>
Lagomorpha	<i>Ochotona</i> sp.	Pika
Rodentia	<i>Myospalax fontanieri</i> <i>Microtus brandtioides</i>	Zokor Vole
Carnivora	<i>Canis lupus</i> <i>Panthera</i> cf. <i>tigris</i>	Wolf Tiger
Proboscidea	<i>Palaeoloxodon</i> cf. <i>naumanni</i>	Naumann's elephant
Perissodactyla	<i>Coelodonta antiquitatis</i> <i>Equus przewalskii</i> <i>Equus hemionus</i>	Woolly rhinoceros Przewalskii's wild horse Kulan
Artiodactyla	<i>Megaloceros ordosianus</i> <i>Cervus elaphus</i> <i>Cervus nippon</i> <i>Spirocerus hsuchiayaocus</i> <i>Spirocerus peii</i> <i>Procapra picticandata</i> <i>przewalskii</i> <i>Gazella subgutturosa</i> <i>Gazella</i> sp. <i>Bos primigenius</i> <i>Sus</i> sp.	Ordos giant deer Elk Sika deer Xujiayao antelope Pei's antelope Przewalskii's gazelle Goitered gazelle Gazelle Auroch Pig
Aves	<i>Struthio</i> sp.	Ostrich

Table 3
Long bone counts of equids (*Equus przewalskii*, *E. hemionus*), and artiodactyls of size 1/2 (*Gazella subgutturosa*, *Cervus nippon*) and of size 3/4 (*Cervus elaphus*, *Bos primigenius*)

Element	Equid				Artiodactyl size 1/2				Artiodactyl size 3/4			
	NISP	MNE ^a	NISP:MNE	MAU	NISP	MNE ^a	NISP:MNE	MAU	NISP	MNE ^a	NISP:MNE	MAU
Humerus	151	30	5.03	15	12	3	4.00	1.5	5	1	5.00	0.5
Radioulna	138	40	3.45	20	11	3	3.67	1.5	7	2	3.50	1
Femur	53	21	2.52	10.5	3	2	1.50	1	2	1	2.00	0.5
Tibia	179	80	2.24	40	3	2	1.50	1	2	1	2.00	0.5
Metapodial	368	130	2.83	32.5	21	11	1.91	1.375	35	12	2.92	1.5
<i>n</i> =	889	301	\bar{X} = 2.95		50	21	2.38		51	17	\bar{X} = 3.00	

^a These counts were rounded up, since different taxon sizes are aggregated.

although preliminary examination of the isolated teeth suggests that the number of equids at Xujiayao may be higher. While *Coelodonta antiquitatis* is also present in the assemblage, the taphonomic analysis of this taxon will be reserved for detailed study at a later point.

One problem that often serves to confound taphonomic analysis of bone surface modifications is the inclusion of specimens with poor cortical bone surfaces (Thompson, 2005). Even though a small proportion of the specimens (<2.3% of the total long bone assemblage) still retained adhering matrix and/or had advanced stages of weathering, the majority had pristine cortical bone surfaces that allowed for the confident identification of most of the marks on the bones.

Under the assumption that nonnutritive phase bone fragmentation can lower the identifiability of long bone fragments, some taphonomic studies (e.g., Marean et al., 2000) have excluded specimens that appear to have been broken when dry (exhibiting right-angle breaks or transverse outlines) from the bone surface modification analyses (see Johnson, 1985; Villa and Mahieu, 1991, for definitions). However, we included these specimens in our study. Our justification is that bone fracture angles can only tell us whether the bone was broken fresh or dry (Johnson, 1985; Outram, 2001). It cannot tell us the biotic or abiotic agent involved in the fracture. The possible biotic agents of interest are hominins or carnivores, both attempting to access the fat-rich marrow cavities of long bones. Even in Marean et al.'s (2000) experimental

studies, which involved fresh bones, there were a number of transverse/right angle fractured specimens. The 95% confidence intervals of transverse/right angle specimens that resulted from carnivore ravaging and human percussion marking overlapped, thus indicating that this breakage pattern is not diagnostic (see Marean et al., 2000: their Figs. 5–6). As such, we have elected to include right angle/transverse broken midshafts, since the relationship between fracture angle/outline and presence/absence of tooth-broken and butchered midshafts is still unclear (but see Capaldo and Blumenschine, 1994; Pickering et al., 2005).

We compared Xujiayao to ethnoarchaeological and experimental datasets derived from North America and East Africa. Even though we have noted elsewhere (e.g., Norton et al., 2007a,b) that it is not ideal to make such comparisons to the Northeast Asian record, we recognize that such comparisons are necessary due to the lack of similar information from East Asia. The primary actualistic [e.g., Blumenschine (1988, 1995), Marean et al. (1992, 2000), Capaldo (1997), Selvaggio (1998)] and Hadza ethnoarchaeology (Lupo and O'Connell, 2002) datasets we used for comparison were chosen because they are replicable in their research designs. Our data may not be exactly comparable because these actualistic and ethnoarchaeological studies included unidentifiable bones in their analyses (Blumenschine, 1995; Marean et al., 2000; Lupo and O'Connell, 2002), while our study specifically excluded these specimens.

Table 4
Taxon size groupings used in this study and applicable for East Asia. See text for more detailed discussion

Taxon size	Weight	Representative taxa	Common name	Geographic range	Reference
0	~1–3 kg	<i>Ochotona</i>	Pika	Central and North Asia, North America	Wilson and Reeder, 2005
1	~15–30 kg	<i>Gazella subgutturosa</i>	Goitered gazelle	Mongolia, Russia, China	Kingswood and Blank, 1996; Wilson and Reeder, 2005
2	~30–120 kg	<i>Cervus nippon</i>	Sika deer	East Asia	Fraser, 1996; Heroldova and Zejda, 2002; Wilson and Reeder, 2005
3	~120–600 kg	<i>Cervus elaphus</i> , <i>Equus hemionus</i> , <i>Equus przewalskii</i>	Elk, Kulan, Przewalskii's wild horse	Elk: Northern hemisphere; Kulan: Asia; Przewalskii's wild horse: Mongolia	Saltz and Rubenstein, 1995; Fraser, 1996; Wilson and Reeder, 2005
4	~600–1500 kg	<i>Bos primigenius</i>	Aurochs	Europe, Asia, Africa	Damuth and MacFadden, 1990
5	>1500 kg	<i>Coelodonta</i> , <i>Palaeoloxodon</i>	Woolly rhino, Straight-tusked elephant	Europe, East Asia	Damuth and MacFadden, 1990

These actualistic studies involved replicating a variety of experimental designs in which hominins and carnivores interacted over meaty and marrow-rich long bones (Capaldo, 1997; Blumenschine and Pobiner, 2006). In the scenario in which hominins were considered to have primary access to the carcass, intact long bones were butchered (defleshed for the meat and the midshafts hammerstone-broken for marrow processing). The butchered bones were then allowed to be accessed by scavenging carnivores. These experimental designs are referred to as “hominin-first”, “hominin-to-carnivore” or “hammerstone-to-carnivore” (Marean et al., 1992, 2000; Blumenschine, 1995; Capaldo, 1997, 1998). In one experimental design, intact bones were left for carnivores to access without processing by hominins. This scenario is referred to as “whole bone-to-carnivore” (Capaldo, 1997). In the case where hominins had secondary access to a carcass, intact long bones were first fed to carnivores (usually hyenas) and then the remainder was processed for the meat and marrow by scavenging hominins. These scenarios are referred to as “carnivore-first”, “carnivore-to-hominin”, or “carnivore-to-hammerstone” (Marean et al., 1992, 2000; Blumenschine, 1995; Capaldo, 1997, 1998). In an extension of these latter scenarios, carnivores were allowed access to the bones following both initial carnivore access and secondary processing by hominins. This experimental design is referred to as “carnivore-to-hominin-to-carnivore” (Selvaggio, 1994, 1998). “Dual-patterned” specimens are ones that display tooth marks and at least one type of butchery mark (either cut marks or percussion marks; Marean et al., 2000). Throughout this paper reference will be made to these experimental studies and terminologies.

Percussion-mark and tooth-mark patterning

A diversity of bone modification studies in actualistic (e.g., Blumenschine, 1988, 1995; Marean and Spencer, 1991; Marean et al., 1992, 2000; Selvaggio, 1994, 1998; Capaldo, 1997, 1998) and ethnoarchaeological settings (e.g., Lupo and O’Connell, 2002; O’Connell et al., 2002) indicate that if hominins have primary access to a carcass, a high proportion of the bones will display percussion marks (27.6–49.2%), while the percentage of long bone midshaft specimens that display tooth marks will be low (7–15%). However, when carnivores have primary access to a carcass, the percentage of tooth-marked midshaft fragments will be high, with percentages ranging between 63–88%. When hominins have secondary access, the frequency of percussion-marked midshafts is low, at 6–12% (see Marean et al., 2000; Blumenschine and Pobiner, 2006; Norton et al., 2007a for review). Many of the Xujiayao long bone midshaft fragments display percussion and tooth marks (Figs. 3–4; Table 5).

Cut-mark patterning

Experimental studies show that the relative frequencies of long bones with cut marks are less indicative of the order of hominin and carnivore access than those of long bone

fragments with percussion marks and tooth marks (Capaldo, 1997; Abe et al., 2002; Lupo and O’Connell, 2002; Egeland, 2003). In general, when examining long bone midshafts, the 95% confidence intervals for cut mark frequencies for hominin-first and carnivore-first experiments overlap (Capaldo, 1997; Lupo and O’Connell, 2002). Ethnoarchaeological cut mark data (human-first) also fall within the range of both types of experimental studies (Lupo and O’Connell, 2002). These confounding data suggest that interpretations of cut mark frequencies should be treated cautiously (see Egeland, 2003; Lyman, 2005).

However, by dividing the midshafts into limb region [upper (humerus, femur), middle (radius, tibia), lower (metacarpal, metatarsal)], the frequencies of cut-marked fragments become more informative (Lupo and O’Connell, 2002). Frequencies of cut-marked upper limb midshafts greater than 20% suggest that the bones were heavily fleshed at the time of processing. Low percentages (<15%) of cut-marked upper limb midshafts indicate that little flesh remained on the bones. More than 40% of the heavily fleshed middle limb shafts display cut marks,² while of the bones initially modified by carnivores less than 15% of the fragments are cut-marked. The percentages of lower limb bones that display cut marks are less useful for deriving behavioral information (Lupo and O’Connell, 2002). The Xujiayao bone collection is dominated by equids, whose upper limbs contain a large quantity of meat, but whose middle and lower limbs have little meat (Outram and Rowley-Conwy, 1998). As a result, the difference in cut mark distribution between the upper and the middle limbs of equids may be expected to be greater than that in bovid/cervid taxa, which have relatively more flesh on their middle limbs (Tables 5–6).

Dual-patterned fragments

The degree of hominin-carnivore competition can be estimated by analyzing these dual-patterned specimens (Selvaggio, 1994, 1998; Capaldo, 1997, 1998; Marean and Kim, 1998; Marean et al., 2000; Egeland et al., 2004). In experimental studies in which carnivores have primary access to a carcass the percentage of midshaft fragments that displays both hominin and carnivore traces will range between 14–42.4%. When hominins have primary access to a carcass that is subsequently scavenged by carnivores, the relative frequency of specimens with both tooth and butchery marks is much lower (4.1–5.7%). If the percentage of bones displaying both types of modification is very low (in the range of the hominin-first experiments or lower), the degree of hominin–carnivore interactions over the same carcasses is likely to have been minimal (Marean et al., 2000; Egeland et al., 2004). In other words,

² In the original paper describing this patterning (Lupo and O’Connell, 2002), “<40%” is used to describe the percentage of cut-marked bones that were heavily fleshed. However, we think this is a copyediting error, since Lupo and O’Connell (2002) also use <15% and between 15–40% to describe the other two cut mark patterns. We interpret Lupo and O’Connell’s (2002) data to be: >40%, 15–40%, <15%.

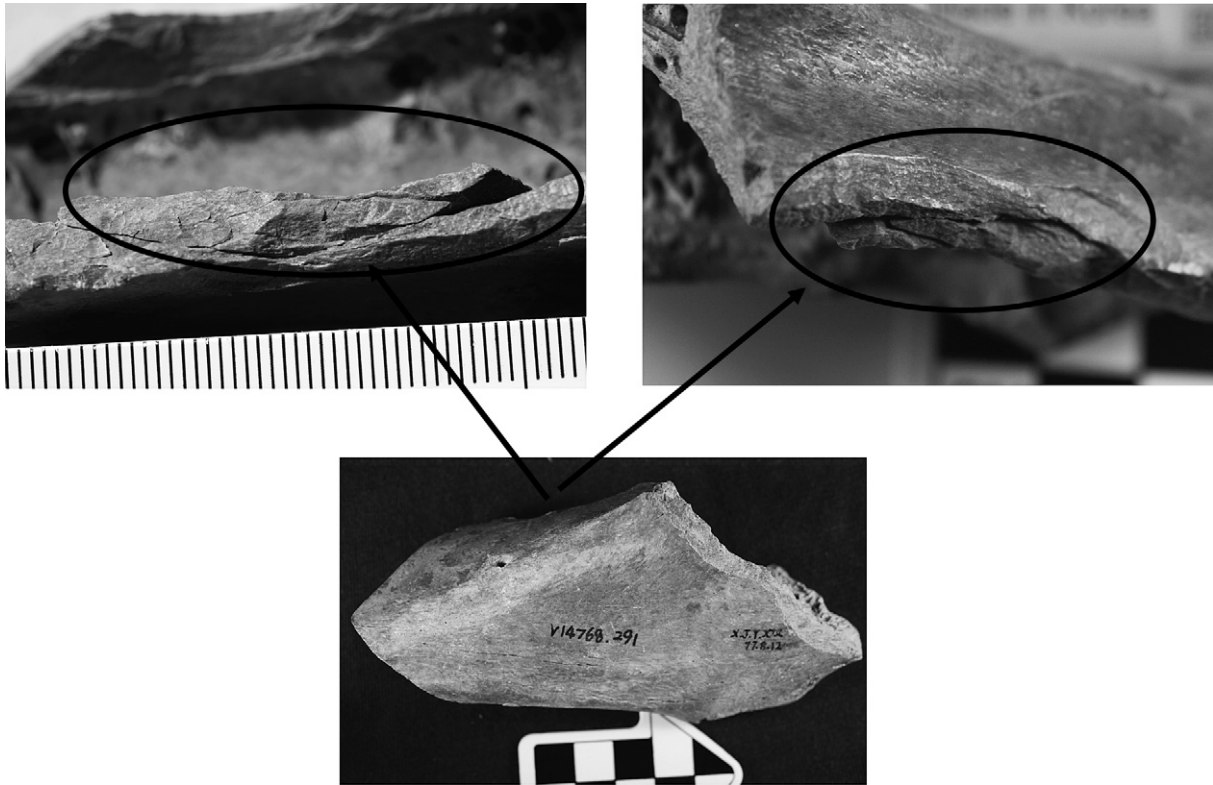


Fig. 3. Example of percussion-marked equid femur midshaft fragment. Note the partially detached flake.

if the percentages are very low (0–6%), then this would suggest: (1) that little remained after hominin utilization for carnivores to scavenge, and (2) that hominins were not under significant time constraints due to competition from other predators. A number of midshaft specimens in this study display evidence of both butchery and carnivore processing (Fig. 5; Table 7).

Fragmentation ratios

Fragmentation ratios (e.g., NISP:MNE) may indicate the degree of bone breakage caused by biotic (e.g., hominin or carnivore processing) and/or diagenetic (e.g., sediment compaction) processes in an archaeofaunal assemblage (Lyman, 1994; Outram, 2001; Pickering and Egeland, 2006). Significant variation

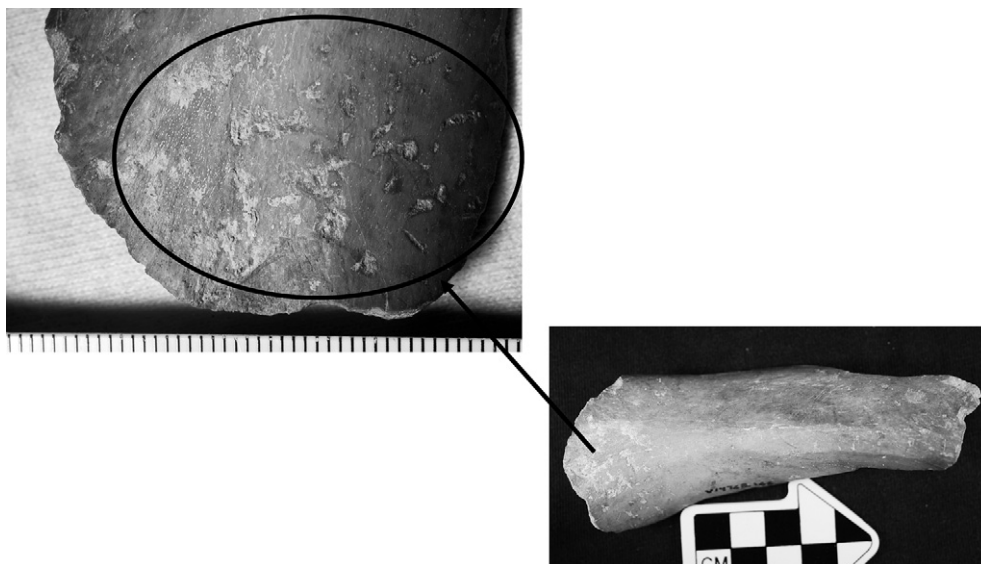


Fig. 4. Example of tooth-marked midshaft fragment. Note that it looks like both epiphyses were chewed off.

Table 5
Midshaft bone surface modification percentages for equid and artiodactyl taxa size 1/2 and 3/4 long bone midshaft fragments^a

Element	Equid				Artiodactyl size 1/2				Artiodactyl size 3/4			
	Cut-mark	Percussion-mark	Tooth-mark		Cut-mark	Percussion-mark	Tooth-mark		Cut-mark	Percussion-mark	Tooth-mark	
Humerus	38.7% (55/142)	28.1% (39/139)	13% (18/138)		41.7% (5/12)	16.7% (2/12)	0% (0/12)		40% (2/5)	50% (2/4)	0% (0/5)	
Radioulna	30.8% (41/133)	33.1% (43/130)	7.5% (10/134)		30% (3/10)	10% (1/10)	0% (0/10)		33.3% (2/6)	50% (3/6)	16.7% (1/6)	
Femur	34% (17/50)	17.4% (8/46)	27.1% (13/48)		0% (0/3)	33.3% (1/3)	0% (0/3)		50% (1/2)	100% (1/1)	0% (0/2)	
Tibia	39.2% (67/171)	35.3% (59/167)	8.7% (15/173)		33.3% (1/3)	33.3% (1/3)	0% (0/3)		50% (1/2)	100% (1/1)	0% (0/2)	
Metapodial	23.5% (80/339)	29.4% (97/330)	12.3% (41/333)		14.3% (3/21)	26.3% (5/19)	4.8% (1/21)		24.2% (8/33)	30% (9/30)	6.1% (2/33)	
Overall percentages =	31.1% (260/835)	30.3% (246/812)	11.7% (97/826)		24.5% (12/49)	21.3% (10/47)	2% (1/49)		29.2% (14/48)	38.1% (16/42)	6.3% (3/48)	

^a Only long bone midshaft fragments that we were 100% confident of the particular marks were included in each analysis (Norton et al., 2007b). In some cases, we could only be 75% (or even less) confident of the mark on the bone. As a result, the overall NISP differs from the NISP that was included in each particular analysis. For example, the overall equid humerus NISP count was 151, but for the cut-mark analysis only 142 specimens were included.

Table 6

Cut-mark frequencies by limb region for Xujiayao equid and Hadza data (from Lupo and O’Connell, 2002). Hadza data are the means with standard deviations in parantheses based on 5 studies. Upper limb = humerus, femur; Middle limb = radius, tibia; Lower limb = metapodials

	Xujiayao	Hadza
Upper limb	37.5% (72/192)	28.8% (6.1)
Middle limb	35.5% (108/304)	30.6% (12.4)
Lower limb	23.5% (80/339)	14.0% (15.9)

in fragmentation ratios may reflect different degrees of bone processing. For instance, in Capaldo’s (1997) experimental studies, he found that the NISP:MNE ratios were always around 1.5 times higher for his hammerstone-to-carnivore samples than his whole bone-to-carnivore experiments. In Capaldo’s experimental assemblages where bones were first hammerstone broken for marrow and then fed to carnivores, the elements were more fragmented than in the collections of complete bones that were fed to carnivores. All things being equal, we should expect no significant difference between the fragmentation ratios if the different taxa or body parts were subjected to similar pre- and postdepositional processes. A general fragmentation ratio (NISP:MNE) is analyzed here (Table 3).

Shaft length and circumference

Dynamic loading (e.g., percussion impact) on long bone midshafts will result in flakes that are smaller and less cylindrical than those produced by the static loading inflicted by carnivore gnawing (Blumenschine, 1995). For instance, in Blumenschine’s (1995: his Table 5) experimental studies the lengths of carnivore-only and hammerstone-only midshafts were significantly different ($t = 2.6, p = 0.01$). Furthermore, in Blumenschine’s (1995: his Table 6) analysis the difference between his hammerstone-only and carnivore-only long bone circumferences is also significant ($\chi^2 = 6.762, df = 2, p = 0.034$). We should expect differences in mean lengths and circumferences between the percussion-marked-only and the tooth-marked-only long bone fragments. No variation would suggest similar pre- and postdepositional processes. Our documentation of shaft circumference followed the methodology described by Bunn (1983) and others (e.g., Assefa, 2006), except that we grouped together shafts with circumferences that were 75% and 100% complete (Tables 8–9) since very few were 100% complete.

Fluvial transport

Experimental studies (e.g., Hanson, 1980; Shipman and Rose, 1983; Behrensmeier et al., 1986) have shown that when bones are fluvially transported or have been exposed to running water for long periods of time their edges will be rounded, shiny, and display randomly oriented shallow striations from abrasion. It is possible that these striations could be mistaken for cut marks (Shipman and Rose, 1983). Lovlie et al. (2001) proposed that the faunal remains from Xujiayao are of allochthonous origin, having been transported to the

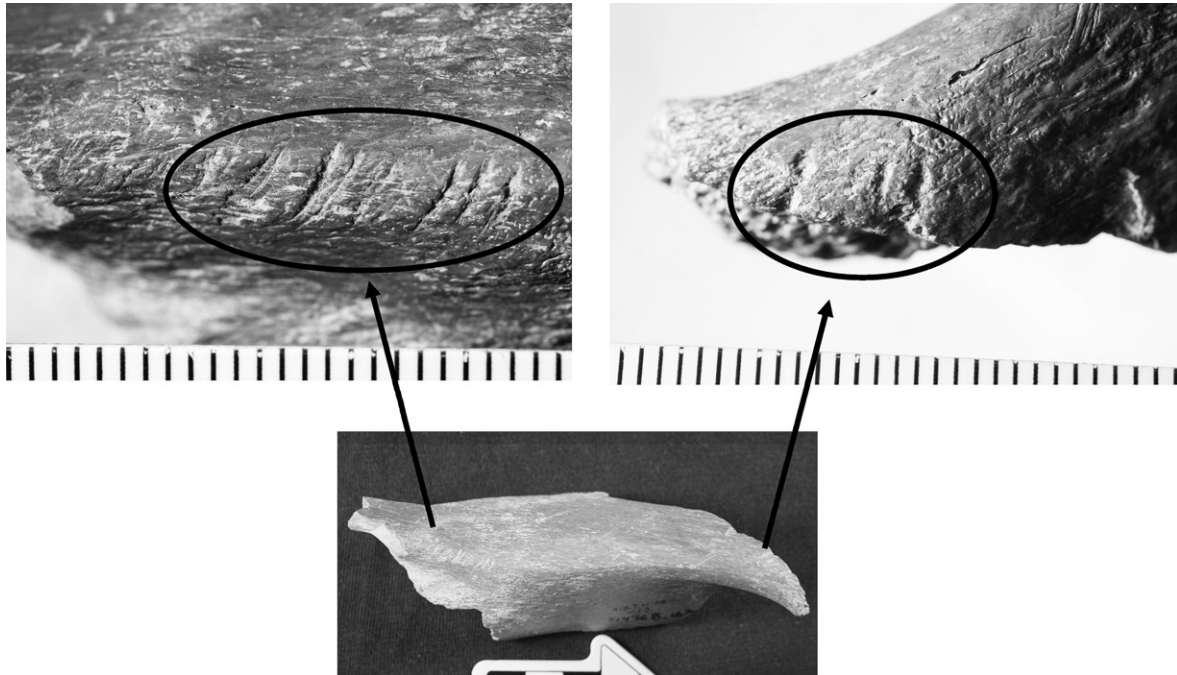


Fig. 5. Example of hominin and carnivore modification on the same equid femur midshaft specimen. Note the cut mark on the diaphysis and the tooth marking located on the metaphysis.

site via fluvial processes. Even though Lovlie et al. (2001) did not present any evidence to support their supposition, we test this hypothesis by examining the evidence for water rounding and abrasion on the long bone midshaft fragments.

Results

Previous studies have shown that the highest MNE counts are derived from the long bone midshafts rather than the epiphyses (Lam et al., 1998; Marean, 1998; Marean and Kim, 1998; Bartram and Marean, 1999; Lam and Pearson, 2005; Assefa, 2006). This is the case with the Xujiayao assemblage; the highest MNE values are from the more dense midshafts (Table 10).

Percussion-mark and tooth-mark patterning

The relative frequencies of percussion-marked midshaft fragments for equids and artiodactyls of all sizes all fall comfortably within the 95% confidence intervals of Blumenschine

(1995), Capaldo (1997, 1998), and Marean et al.'s (2000) experiments in which hominins had primary access to the long bones (Fig. 6). The percentage of percussion-marked fragments are all well above the range of Selvaggio's (1994, 1998) actualistic studies in which carnivores had initial access to the appendicular elements.

The percentages of tooth-marked midshaft specimens for equids and artiodactyls of all sizes fall within the 95% confidence intervals for primary hominin access to the long bones (Fig. 7), based on the data provided by the experimental studies of Blumenschine (1995) and Capaldo (1997, 1998), as well as the ethnoarchaeological data derived from the Hadza (Lupo and O'Connell, 2002). All of the Xujiayao tooth mark frequencies are well below the range of the carnivore-first studies of Blumenschine (1995), Capaldo (1997, 1998), and Selvaggio (1994, 1998).

Cut-mark patterning

The Xujiayao cut mark frequencies for equids and all artiodactyls fall within the ranges for both the hominin-first and

Table 7
Dual-patterned data. Cut-mark + tooth-mark, percussion-mark + tooth-mark percentages for long bone midshaft fragments

Element	Equid		Artiodactyl size 1/2		Artiodactyl size 3/4	
	Cut-mark + tooth-mark	Percussion-mark + tooth-mark	Cut-mark + tooth-mark	Percussion-mark + tooth-mark	Cut-mark + tooth-mark	Percussion-mark + tooth-mark
Humerus	4.5% (6/134)	1.5% (2/131)	0% (0/12)	0% (0/12)	0% (0/5)	0% (0/4)
Radioulna	0.8% (1/128)	0.8% (1/125)	0% (0/10)	0% (0/10)	16.7% (1/6)	0% (0/6)
Femur	17.4% (8/46)	6.8% (3/44)	0% (0/3)	0% (0/3)	0% (0/2)	0% (0/1)
Tibia	2.4% (4/169)	3.6% (6/165)	0% (0/3)	0% (0/3)	0% (0/2)	0% (0/1)
Metapodial	3.1% (10/319)	2.6% (8/311)	0% (0/21)	0% (0/19)	0% (0/32)	0% (0/29)
Overall percentages =	3.6% (29/796)	2.6% (20/776)	0% (0/49)	0% (0/47)	2.1% (1/47)	0% (0/41)

Table 8
Descriptive statistics of the lengths of tooth-marked only and percussion-marked only equid long bone midshaft fragments

Mark	n	Mean	Std. deviation
Tooth-mark	91	92.4	25.6
Percussion-mark	224	97.5	29.4

carnivore-first studies (Fig. 8). When the cut mark data are grouped by limb region, all of the Xujiayao equid data points are above the means and in the upper part of the range of the Hadza data (Fig. 9). There is significant variation between the distributions when examining all three regions ($\chi^2 = 15.341$, $df = 2$, $p = 0.0005$). Since the cut mark frequencies between the upper and middle regions are not significantly different ($\chi^2 = 0.198$, $df = 1$, $p = 0.656$), the high percentage of cut-marked metapodials is primarily influencing the distribution. Even though the frequency of lower limb bones that display cut marks is above the average from the Hadza data, the percentage is still lower than that for the upper and middle long bones, as might be expected due to the paucity of flesh in this bone region.

Dual-patterned fragments

The percentage of equid midshaft specimens that have both tooth marks and percussion or cut marks falls within the range of Capaldo's (1997, 1998) hammerstone-to-carnivore actualistic studies and is close to Marean et al.'s (2000) experimental data (Fig. 10; Table 7). Both frequencies [cut mark + tooth mark (3.6%) and percussion mark + tooth mark (2.6%)] are well below the 95% confidence intervals of Capaldo (1997, 1998) and Selvaggio's (1994, 1998) experimental studies in which carnivores had primary access to the long bones. The percentages of modified bone for the artiodactyls are lower than for equids.

Fragmentation ratios

When including all of the ratios for the different skeletal elements, the between-group (equid, artiodactyl Size 1/2, artiodactyl Size 3/4) variation in the NISP:MNE fragmentation ratios is not significantly different ($F = 0.483$, $df = 2$, 12 , $p = 0.628$; Table 3). However, when comparing only the forelimb and hind limb regions of all taxa combined (and excluding the metapodials), the forelimb ratios are significantly higher ($t = 6.317$, $p = 0.0005$). When including the metapodials as a separate region, the forelimb ratios are still

Table 9
Number of tooth-marked only and percussion-marked only equid long bone midshaft fragments by circumference

Circumference	Percussion-marked only bone	Tooth-marked only bone
25%	46	20
50%	130	54
75%–100%	48	15
Total =	224	89

Table 10
MNE and %MNE by bone region for equids

	Humerus	Radius	Femur	Tibia	Metapodials
MNE					
Proximal epiphysis	0	5	1	15	35
Diaphysis	30	40	21	80	122
Distal epiphysis	12	3	1	4	41
%MNE					
Proximal epiphysis	0.0%	12.5%	4.8%	18.8%	28.7%
Diaphysis	100.0%	100.0%	100.00%	100.0%	100.0%
Distal epiphysis	40.0%	7.5%	4.76%	5.0%	33.6%

significantly higher ($F = 21.099$, $df = 2$, 12 , $p = 0.0005$). This may indicate heavier processing of the forelimbs compared with the hind limbs and metapodials.

Shaft length and circumference

There is no significant difference between the lengths of the equid long bone fragments that display only tooth marks and those that display only percussion marks ($t = 1.44$, $p = 0.151$). The equid shaft circumference distributions for the percussion-marked only and tooth-marked only bones are also not significantly different ($\chi^2 = 0.851$; $df = 2$; $p = 0.653$).

Fluvial transport

Only 1.5% of the equid and 2.5% of the artiodactyl limb bones display any sign of wear from continuous fluvial activity in the form of water rounding and shine (Fig. 11). Evidence of trampling and/or sedimentary abrasion, however, is present on the specimens (equids: 22.8%; artiodactyls: 23.2%; Fig. 12).

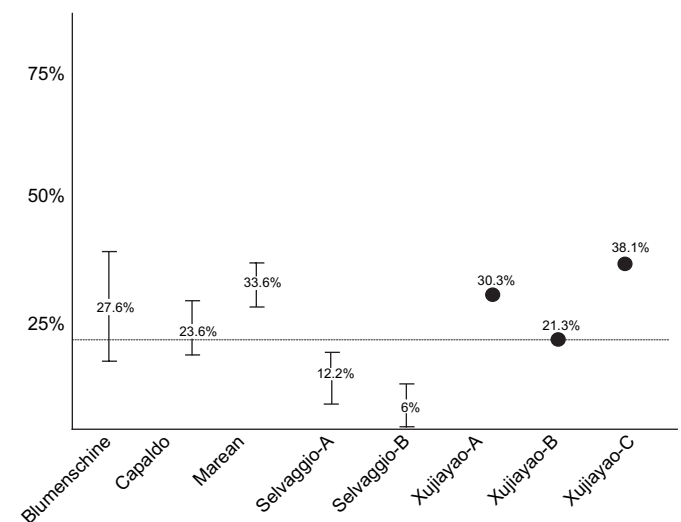


Fig. 6. Percussion mark percentages from actualistic studies on long bone midshaft fragments (Selvaggio, 1994, 1998; Blumenschine, 1995; Capaldo, 1997, 1998; Marean et al., 2000) compared with Xujiayao data. Mean percentages with 95% confidence intervals are given for Blumenschine, Capaldo, Marean, and Selvaggio's studies. Blumenschine = hominin-to-carnivore; Capaldo = hominin-to-carnivore; Marean = hominin-to-carnivore; Selvaggio-A = carnivore-to-hominin; Selvaggio-B = carnivore-to-hominin-to-carnivore; Xujiayao-A = equids; Xujiayao-B = artiodactyl Size 1/2; Xujiayao-C = artiodactyl Size 3/4.

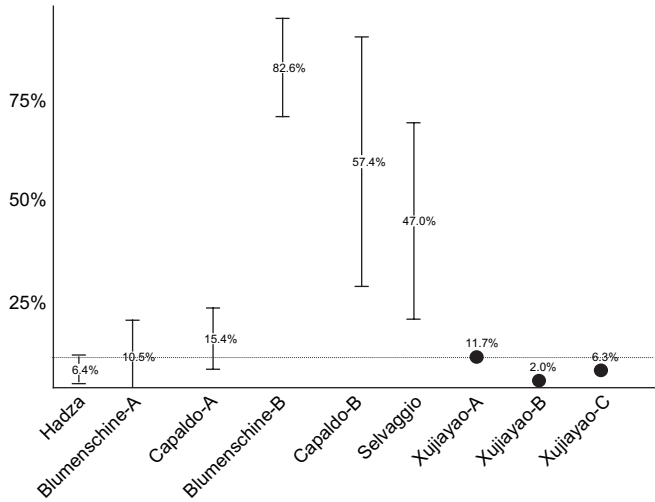


Fig. 7. Tooth-mark percentages on long bone midshaft fragments from ethnoarchaeological and actualistic studies (Selvaggio, 1994, 1998; Blumenschine, 1995; Capaldo, 1997, 1998; Lupo and O’Connell, 2002) compared with Xujiayao data. Mean percentages with 95% confidence intervals are given for Blumenschine, Capaldo, and Selvaggio’s studies. Marean et al.’s (2000) data are not graphed here, though they overlap with the other actualistic studies. Blumenschine-A = hominin-to-carnivore; Capaldo-A = hominin-to-carnivore; Blumenschine-B = carnivore-to-hominin; Capaldo-B = carnivore-to-hominin; Selvaggio = carnivore-to-hominin; Xujiayao-A = equids; Xujiayao-B = artiodactyl Size 1/2; Xujiayao-C = artiodactyl Size 3/4.

Discussion

Both the percussion mark and tooth mark data indicate that the Xujiayao hominins likely had primary access to the intact long bones of equids and artiodactyls. The frequency of percussion-marked size 1/2 artiodactyl long bone midshafts (21.3%) falls comfortably within the range of the hominin-first

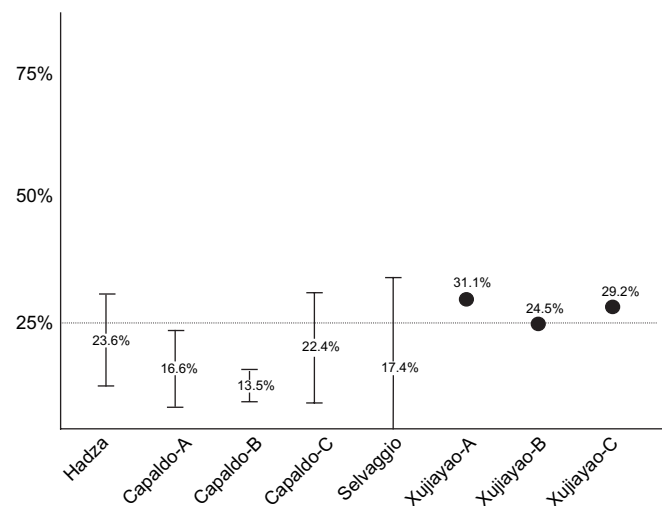


Fig. 8. Cut-mark percentages on long bone midshaft fragments from ethnoarchaeological and actualistic studies (Capaldo, 1997; Lupo and O’Connell, 2002) compared with Xujiayao data. Mean percentages with 95% confidence intervals are given for Capaldo and Lupo and O’Connell’s studies. Capaldo-A = hominin-to-carnivore; Capaldo-B = hammerstone-to-carnivore; Capaldo-C = whole bone-to-carnivore; Xujiayao-A = equids; Xujiayao-B = artiodactyl Size 1/2; Xujiayao-C = artiodactyl Size 3/4.

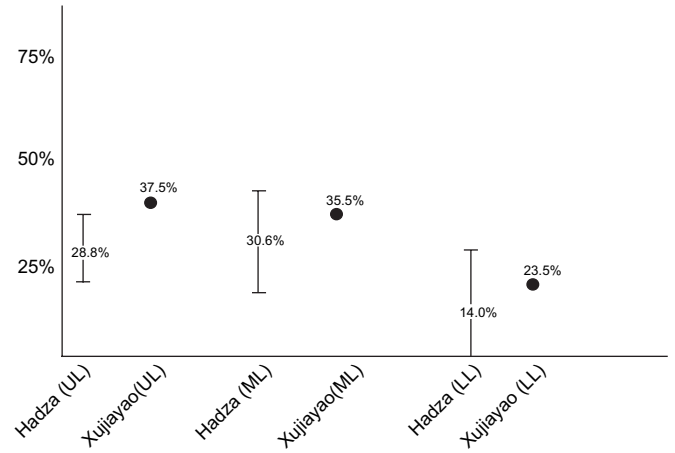


Fig. 9. Cut-mark percentages on long bone midshaft fragments by bone region from ethnoarchaeological studies (Lupo and O’Connell, 2002) compared with Xujiayao equid data. Mean percentages with 95% confidence intervals are given for Lupo and O’Connell’s studies. UL = upper limbs; ML = middle limbs; LL = lower limbs.

experimental studies. The frequency of percussion-marked equid (30.3%) and size 3/4 artiodactyl (38.1%) long bone midshafts falls well above the range for the carnivore-first studies. The frequency of tooth-marked long bone midshafts, regardless of taxon or body size (equids had highest count: 11.7%), is within the range of the hominin-first datasets, and well below the range of the carnivore-first studies.

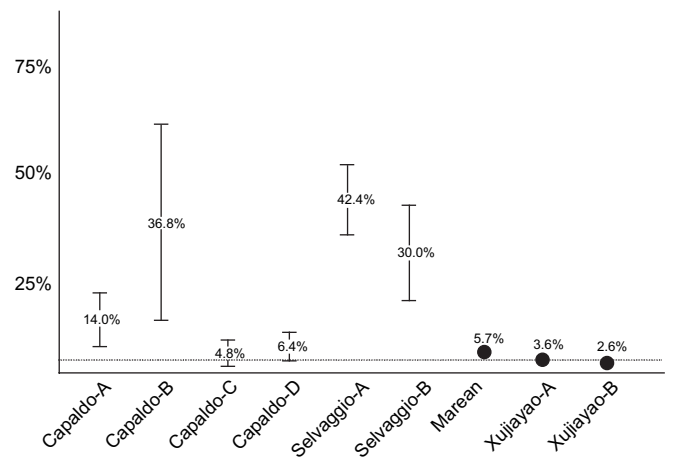


Fig. 10. Cut-mark (CM) + tooth-mark (TM), percussion-mark (PM) + tooth-mark percentages from actualistic studies on long bone fragments (Selvaggio, 1994, 1998; Capaldo, 1997, 1998; Marean et al., 2000) compared with Xujiayao equid data. Mean percentages with 95% confidence intervals are given for Capaldo and Selvaggio’s studies. Capaldo-A = TM + CM, whole bone-to-carnivore, taxon size 1–3; Capaldo-B = TM + CM, whole bone-to-carnivore, taxon size 3; Capaldo-C = TM + CM, hammerstone-to-carnivore, taxon size 1–3; Capaldo-D = TM + CM, hammerstone-to-carnivore, taxon size 3; Selvaggio-A = TM + CM and/or PM, carnivore-to-hominin, taxon size class 1–4; Selvaggio-B = TM + CM and/or PM, carnivore-to-hominin-to-carnivore, taxon size class 1–4; Marean = TM + PM, hammerstone-to-carnivore, taxon size class 1–2; Xujiayao-A = TM + CM for equids; Xujiayao-B = TM + PM for equids. The data for the Xujiayao artiodactyls are not graphed here, because the percentages are even lower than the equid data (3 of the 4 categories registered 0%).



Fig. 11. Example of water-worn equid metapodial fragment. Note the smooth, shiny, well-rounded surface.

In general, cut-mark frequency data are more difficult to interpret than tooth and percussion mark data (Egeland, 2003; Lyman, 2005). However, in the Xujiayao case (particularly among the equids) the percentage of cut-marked aggregate limb midshafts (31.1%) is above the mean of both the hominin-first and carnivore-first experimental datasets. The cut mark frequency data for equids sorted into limb regions (upper, middle, lower) are all well above the means from ethnoarchaeological studies. This pattern strongly suggests that hominins were likely processing the upper limb bones when most or all of the meat was still attached to the bone. The high percentage of cut-marked fragments representing the almost meatless middle (35.5%) and lower (23.5%) equid limb bones are likely due to disarticulation and skinning activity, rather than defleshing. The above-average frequency of cut-

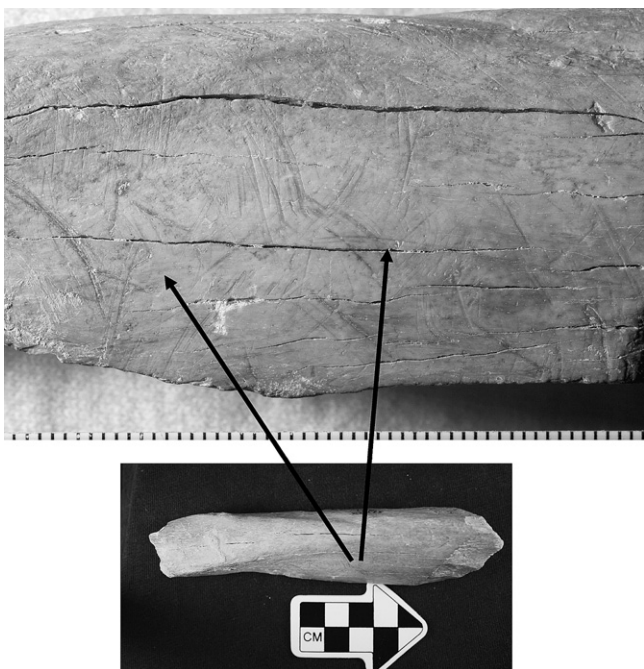


Fig. 12. Evidence of trampling/abrasion on an equid tibia fragment. Note the randomly oriented, shallow striations.

marked midshafts may indicate that equid long bones need to be more intensively prepared before accessing the marrow cavities as well.

The hominin-carnivore interdependence dataset (tooth mark + butchery mark) indicates that carnivores contributed few of the equid long bones to the site and likely only modified the hominin-deposited remains after the bones had been butchered. The frequency of butchery-marked long bone midshaft fragments is within the range of variation of the hominin-first experimentally-derived faunal assemblages. In only one dataset (cut marks + tooth marks on equid femora: 17.4%) does the percentage of marked bone fall above the range of the hominin-first experiments and within the range of the carnivore-first datasets. A plausible explanation for this is that even though the equid femur falls in the middle of the meat index (Outram and Rowley-Conwy, 1998), it has the highest rank on the standardized marrow index. As such, even after being fully processed, the femur midshafts may still have retained enough nutrients to attract scavenging carnivores.

The fragmentation ratios of the limb bone midshafts do not differ significantly between taxonomic groups. However, when comparing forelimbs with hind limbs (and lower limb bones as well), there is significant variation. The upper forelimbs are more highly fragmented than the hind limbs and lower limb bones. Since there are no significant differences in the bone density of equid and artiodactyl long bone midshafts (Lam et al., 1999), density-mediated processes are not likely the primary reason for this difference.

It is interesting to note that even though the equid humeri and radioulnae are relatively low on the standardized food utility index [(S)FUI] and in the middle of the standardized marrow index (Outram and Rowley-Conwy, 1998) they have the highest fragmentation ratios. Another intriguing observation is that the fragmentation ratios of the metapodials, which are very low on the (S)FUI, are higher than the ratios for the hind limbs. It is likely that the Xujiayao appendicular elements were completely processed on site for both meat and marrow. Since equid marrow contains high levels of polyunsaturated fats, some of the marrow is normally in liquid form and tends to become rancid more quickly (Outram and Rowley-Conwy, 1998; Levine, 1998, and references therein). It would have been in a carnivore's best interest to process the equid long bone marrow cavities as quickly as possible. Even though the same pattern presents itself for the artiodactyls, small sample sizes warrant caution in interpreting the latter dataset in the same way as the more robust equid dataset. More intense processing of the less valuable limb elements (e.g., metapodials) likely indicates some degree of food stress by either hominins or carnivores.

Scavenging carnivores will have little interest in a long bone fragment that is devoid of its meat and marrow. Carnivores will focus on the epiphyseal ends of the long bones in order to consume whatever grease remains. Analysis of the lengths and circumferences of percussion-marked only and tooth-marked-only fragments found no statistically significant differences. We interpret this to mean that carnivores regularly accessed broken long bone midshaft sections after hominin

processing occurred. This interpretation is further supported by the very low overall number of tooth-marked equid midshafts (11.7%). Even though *Crocota crocota* is present in middle and late Pleistocene deposits in Northeast Asia (Qi, 1990), the only carnivores identified at Xujiayao were *Canis lupus* and *Panthera tigris*. A dearth of hyena activity at the site is likely to be at least one of the reasons for the relatively low percentage of tooth-marked midshafts.

Even though it was proposed that the Xujiayao bones may have been secondarily deposited (see Lovlie et al., 2001), few of the bones (e.g., equids: 1.5%) display evidence of having been subjected to fluvial processes. In addition, experimental studies (e.g., Fiorillo, 1989) indicate that almost 50% of an assemblage can display the random striation patterning that sedimentary abrasion or trampling causes on bones. Since this study focuses on the long bone midshafts, we were not able to conduct a more detailed analysis of the effect of fluvial processes. However, in the taphonomic study of the late Pleistocene Japanese Hanaizumi faunal collection (Norton et al., 2007b), 38% of the assemblage displayed abrasion, which fell within the range of the experimental studies. The Hanaizumi taphonomic interpretations were further supported by the skeletal part profile analysis that suggested fluvial transport. The frequency of abraded/trampled bones at Hanaizumi is almost twice that of Xujiayao (22–23%). The Xujiayao faunal assemblage is likely primarily of autochthonous origin. Analysis of the skeletal part profiles should clarify this question of origins.

Conclusions

The successful survival of Early Paleolithic hominins in more northern latitudes was predicated on the ability to reliably exploit animal resources. Multiple lines of taphonomic evidence presented here indicate that the Xujiayao archaic *Homo sapiens* were able to procure a regular supply of protein and fat through primary access of the intact artiodactyl and especially equid long bones. In particular, the percussion- and tooth-mark frequency data all fall within the range of the ethnoarchaeological and actualistic human/hominin-first datasets and well outside the range of the carnivore-first models. The cut-mark patterning is less clear, although suggestive of a hominin-first scenario.

The low proportion of midshafts with both butchery and carnivore tooth marks also indicates that hominins likely had primary access to the meaty and marrow-rich intact long bones, because these frequencies fall well below the range of the carnivore-first experimental studies. Carnivores would later scavenge what was left over (i.e., the grease-filled epiphyseal ends) after the site was abandoned. This is further supported by the fact that the highest MNE counts are derived from the midshafts, indicating that many of the epiphyses were removed by carnivores and/or other density-mediated processes (e.g., sediment compaction). The extent of hominin boiling technology during the Early Paleolithic in Northeast Asia is currently not known, so we are unable to determine whether hominins were able to access the long bone grease. The dual-patterned data also suggests that carnivores

contributed few intact bones to the site on their own. There is no statistical difference between the lengths and circumferences of long bone fragments with only percussion marks and those with only tooth marks. Since scavenging carnivores will not appreciably modify long bones that are largely devoid of any nutrients, the carnivores at Xujiayao were likely initially encountering similar sized fragments.

This analysis indicates that some time during the latter part of the Early Paleolithic hominins in the western Nihewan Basin had regular primary access to meaty and marrow-rich long bones, particularly those of equids. This study adds to an increasing body of recent taphonomic analyses (e.g., Norton et al., 2007b) that address the nature of hominin–carnivore interactions during the Plio-Pleistocene in the more northerly latitudinal regions of East Asia.

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