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ZOOARCHAEOLOGICAL AND TAPHONOMIC ANALYSIS OF THE FAUNAL

ASSEMBLAGE FROM TANGZIGOU, SOUTHWESTERN CHINA

A Dissertation in

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by

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ABSTRACT

This dissertation research is a zooarchaeological and taphonomic analysis of the faunal assemblage from Tangzigou, an Early Holocene open-air site in Yunnan Province, southwest China. The goal of this study was to reconstruct the foraging behavior of Tangzigou people in order to investigate whether there were archaeological signs of resource stress and/or intensification in post-Pleistocene southwestern China. This research contributes to our current understanding of the timing and process of the subsistence shift from foraging to agriculture during the Pleistocene-Holocene transition.

No evidence of resource intensification was found in the Tangzigou assemblage. Data used to evaluate the resource stress hypothesis were derived from the analysis of the skeletal element representations, mortality profiles, bone breakage patterns, and bone surface modifications of ~9000 mammalian bone fragments. Large-scale comparative datasets were produced from observations of modern antlers and experimental studies on modern cervid/bovid phalanges to accurately document the various types of modifications. This was done in order to confirm or dispute the existence of antler tools at Tangzigou, and to explain the meaning of intensively broken phalanges in the Tangzigou assemblage.

The interpretation here is still a hypothesis based on just one site from a single time period that requires further testing. A larger sample is essential for inter-site and diachronic comparisons to understand the timing and process of subsistence shift. Only then, can an accurate portrait of the human subsistence strategies from Tangzigou emerge. This research is a step toward fulfilling that goal.

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Chapter 1

Introduction

The nature of the Pleistocene-Holocene transition has been extensively studied by the anthropologists because it is when the subsistence transition from hunting and gathering to farming (cultivation plants and herding animals) occurred in a number of places on the planet. Various hypotheses have been proposed to explain the motivation behind this subsistence shift. Although these hypotheses vary in details, most of them view the transition as an adaptive response to the external pressure, such as climate change and population growth, and /or to the internal changes in social organization (Smith, 1998).

It is essential to understand the process and timing of the subsistence transition in order to answer the ultimate question of why. This led researchers to focus on documenting the paleoenviromental changes, finding the earliest domesticates, and understanding the associated archaeological materials, such as pottery and sedentary villages. Research in the Levantine Epipaleolithic (the equivalent of the European Late Upper Paleolithic) is a case in point for such studies (e.g., Stiner, 2001; Bar-Oz and Dayan, 2003; Davis, 2005; Stutz et al., 2009). Large-scale, comparative, intra-regional archaeological studies from the Levant that span several millennia have provided a high resolution picture of the subsistence shift during the Pleistocene-Holocene boundary.

China is generally accepted as an independent center of such a subsistence transition. Archaeological research has focused on the two major river valleys, the Yellow River in the northeast and the Yangzi River in the southeast. A number of Early Holocene sites yielded a

large quantity of domesticated plants and animal remains with sedentary villages and pottery (e.g., Yuan and Flad, 2002; Barton et al., 2009; Crawford, 2009). These sites are generally considered to be Neolithic sites in China. For example, the site of Cishan in northeastern China along the Yellow River valley is radiocarbon dated to between ca. 10,300 and ca. 8,700 calibrated years BP. Numerous millstones, houses, pottery, faunal remains and 88 storage pits with significant quantities (~ 109 m^3) of domesticated grain crop remains were found, suggesting that food production was well established by 8,000 BP in northeastern China (Lu et al., 2009).

In southeastern China, there are several Late Pleistocene-Early Holocene sites along the Yangzi River valley that have yielded pottery, stone/bone tools, and plant/animal remains, such as Yuchanyan (Hunan Province), Xianrendong, Diaotonghuan (Jiangxi Province), Zengpiyan (Guangxi Province), and Kuahuqiao (Zhejiang Province) (Zong et al., 2007; Zhang and Hung, 2008; Prendergast et al., 2009 and references therein). Among these sites, Kuahuqiao in the Lower Yangzi River is the best known site; it is dated between 7,700 and 7,550 cal BP. It yielded domesticated rice, a wide variety of wild plants, a dugout canoe, bamboo and wooden tools, and rich faunal materials (Zong et al., 2007). Because both wild and domesticated plants and animals were found at this single site, further studies on the Kuahuqiao assemblage will shed light on the subsistence transition in southeastern China. In sum, archaeological data from the sites along the Yellow and Yangzi River valley show that the transition from a mobile, foraging-based economy to a sedentary, agriculturally-based one started during the Pleistocene-Holocene boundary in eastern China.

Nevertheless far fewer archaeological studies have been conducted in southwestern China, making it difficult to understand the timing and process of this subsistence shift. Southwest China, especially Yunnan Province, warrants further archaeological studies due to its very different environmental settings compared to those of the middle and lower reach of the Yellow and Yangzi River valleys in eastern China. Instead of a lowland floodplain setting, Yunnan is characterized by its steep and high mountain ranges and its high altitude (average 1,980 m high). Unlike eastern China, the earliest evidence of the Neolithic culture appears much later in the history around 4,000 BP at Baiyancun site in northern Yunnan (Higham, 2002). Linguistic and pottery style analysis indicate that the sedentary life style with rice agriculture was introduced to Yunnan and Southeast Asia from the lower Yangzi valley around 4,000 BP (Higham, 2002), but this hypothesis requires further testing using plant and animal remains from additional archaeological sites.

Human subsistence patterns are influenced by the interaction between humans and the regional environment. Thus, it is likely that significant differences in the local environment will lead to a different subsistence strategy. This may explain why the so called Neolithic culture (pottery, sedentary villages, and domesticated plants and animals) did not appear simultaneously as a "revolutionary package" in various parts of the world. For example, the Jomon people in Japan, who occupied the Japanese archipelago between 14,000 to 2,500 years ago, started to use pottery in the Late Pleistocene and settled down along the coastal area but did not domesticate plants and animals (Habu, 2004). The people of California were another group of sedentary hunter-gatherers until around 4,000 BP (Wohlgemuth, 1996). The hunting and gathering life style was probably suitable for these groups because of the

abundant marine resources that helped to sustain the population. The situation was quite different in the Levant. The Late Pleistocene-Early Holocene Levant is characterized by an environment of highly seasonal and semi-arid open forests and grasslands (Bar-Oz, 2004). Permanent agricultural villages with sophisticated food production economy were well established in the Levant by 8,000 BP in the absence of pottery (Smith, 1998; Kuijt, 2000). Given the diversity of subsistence strategies and in the timing of changes worldwide, we cannot assume that people in Yunnan followed the same trajectory as the people from the eastern lowland China, the Levant, or Japan. New data on subsistence pattern from the Early Holocene of Tangzigou site in Yunnan will add different perspectives to our current understanding of the diverse nature of human interaction with the environment.

One of the hypotheses offered to explain the transition from hunting and gathering to farming focuses on demographic shift in human groups. First proposed by Binford (1968) and further elaborated by Flannery (1969), the "marginality hypothesis" viewed population growth as the most important causal factor to understand the origins of food production. If the equilibrium between humans and the natural resources is disturbed by climatic change and/or population growth, then some people will be forced to move to a marginal area. The group who moved into a less optimal region with a lower carrying capacity will start to put pressure on the local environment, which will eventually cause subsistence changes toward the domestication of plants and animals (Watson, 1995). The strength of this hypothesis is that it can be tested with data from faunal assemblages. If the origins of plant and animal domestication is primarily the product of subsistence stress, that will be reflected in the archaeological record in the form of resource intensification.

Resource intensification can be defined as "the extraction of increased amounts of energy from a given area at the expense of foraging efficiency" (Munro, 2009: 141). The commonly accepted signs of resource intensification from zooarchaeological assemblages are dietary expansion and intensive carcass processing. Generally known as the "broad spectrum revolution" (Flannery, 1969), increasing dietary breadth can be achieved by adding species that were largely ignored before, e.g., animals with small energy return due either to their small body sizes or to their elusive behavior (Stiner, 2001; Steele and Klein, 2009). An alternative strategy from increasing the number of food items could be more intensive processing of individual carcasses to extract more calories from marrow and grease (Munro, 2004; Munro and Bar-Oz, 2005; Steele and Klein, 2009). The fragmentation ratio of the animal bones and the relative abundance of various animal species can be used as archaeological signatures of resource stress indicative of intensification. There are numerous archaeological assemblages that show evidence of intensification immediately before the onset of domestication especially in the Near East and middle- and high latitude Europe (Binford, 1968; Stiner, 2001; Bar-Oz and Dayan, 2003; Davis, 2005; Stutz et al., 2009).

In this study, the Tangzigou faunal assemblage was analyzed to investigate whether there were signs of resource intensification/stress. This was done by carrying out a series of zooarchaeological and taphonomic analyses including studies of the skeletal element representation, mortality profile, bone breakage pattern, and bone surface modification. I focused on evaluating evidence for resource intensification not because resource intensification is necessarily the precursor to the subsistence shift from hunting and gathering

to farming in all parts of the world, but because this hypothesis has been put forward to explain features of faunal assemblages at the Pleistocene-Holocene boundary elsewhere. Thus, analysis of the Tangzigou assemblage will provide a test of this hypothesis and its applicability to southwestern China.

1-1. The Tangzigou site in Yunnan Province, southwest China

Environmental setting of the Tangzigou site

Yunnan Province in southwestern China covers a large area (~394,000km^2) and shares its borders with Vietnam and Laos to the south and with Burma to the west (Figure 1.1). Yunnan is one of the most ecologically and culturally diverse regions outside of the tropics, with environments ranging from tropical evergreen forests in the southeast to towering Himalayan peaks and alpine herbfields, and shrublands lying above *Picea-* and *Abies-*dominated forests in the northwest (Walker, 1986; Chaplin, 2005). The high ecological and anthropological diversity has evolved because of "the great range of physical landforms and environmental conditions that exist in the province" (Jablonski et al., 2003: 209). The Hengduan mountain range in western Yunnan comprises of three north-south running, parallel mountain chains. These high peaked mountains were formed during the Mesozoic and accentuated by the Himalayan uplift in the later Tertiary (Jablonski et al., n.d.). The three mountain chains are separated from west to east by the Salween (the Nujiang), Mekong (Lancang), and Yangzi (Jinsha) rivers originating from the Qinghai-Tibetan (Xizang) Plateau, forming extremely deep river gorges (average 2000 m in the northern half) channeling large rivers with strong currents (Chaplin, 2005).

One of the most remote areas in Yunnan is the Gaoligong mountain chain (or

Gaoligongshan), the westernmost chain of the Hengduan mountains. It has been recognized

as a World Heritage Site (UNESCO 2003) for its biodiversity. These north-south conduits

have served as dispersal routes for the plants and animals and also as geological barriers to

the east-west migration. This unique geological structure created ecological shelters for

various plants and animals including humans since the later Tertiary. For instance, adapids

and hominoids occur in the fossil record in the Miocene and Pleistocene, long after they

disappeared elsewhere, indicating that subregions of Yunnan served as long-term

environmental refuges (Jablonski, 2005). This may also explain the high concentration of the

Chinese ethnic minority groups (> 50%) in Yunnan (Goodman, 2006).

On the southern edge of the Gaoligong mountain chain lies the open-air site, Tangzigou (N

25º 1´ 31″, E 99º 0´ 28″; 1360 meters above sea level) (Figure 1.1). It is a flat area of ~300

m^2 located on top of a small hill along the Pupiao River in the Pupiao Basin in Baoshan

Prefecture. The Pupiao Basin is one of the north-south trending basins that parallel the

Gaoligong mountain chain that formed during the Miocene. Filling of the basin with lignites

and other sediments was completed by the Pliocene, and erosion of the basin coupled with

dissection by young, sediment-rich rivers commenced in the Pleistocene.

At the time the site of Tangzigou formed, there appears to have been a small lake to the

northwest and an extensive wetland along the Pupiao River in front of the site (G. Chaplin,

pers. comm.). The habitat preferences of the micromammal species recovered from

Tangzigou indicate that the area was covered with subtropical forest, including pockets of

moist bamboo forest, at the time the assemblage accumulated (L. Flynn, pers. comm.). The

broad range of rock sizes and sediment particle shapes found at Tangzigou are indicative of a

colluvial deposit. The current geological setting of the Pupiao Basin and the state of bone

preservation (see Chapter 2 for detailed description) also suggest that the faunal assemblage

has moved only a short distance downslope from the original deposition site, probably by

runoff during multiple rainstorms (R. Graham, pers. comm.). This suggests that the

vegetation was sparse or at least not dense at the site, allowing the sediments to be washed

away.

Figure 1.1. (Top) Map of Tangzigou area in East Asia. Light green is Yunnan Province and yellow area is Baoshan county. (Bottom) Close up map of Tangzigou (star). Courtesy of George Chaplin.
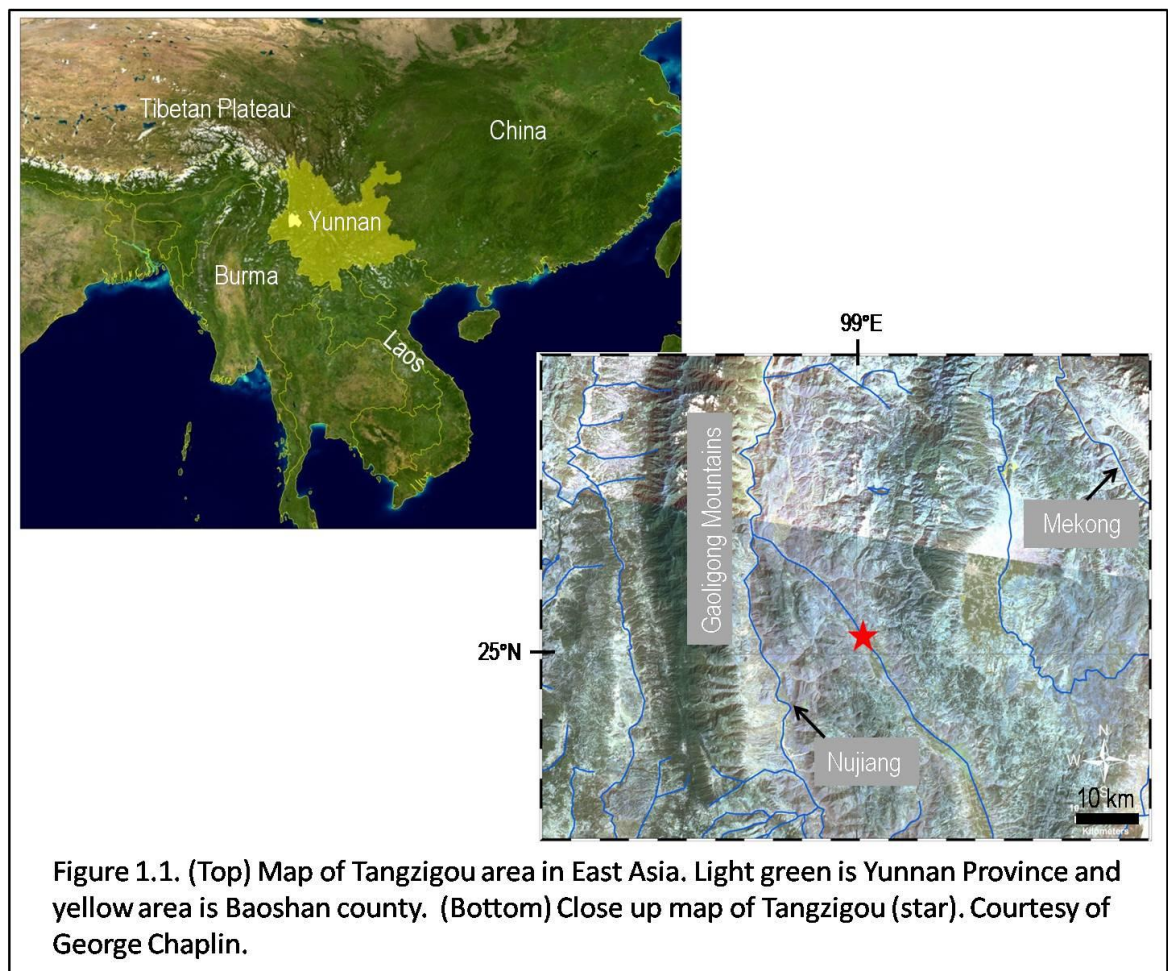
Tangzigou was probably preferred by prehistoric people as a place to process the animal carcasses for two reasons. First, the elevated setting of the site in a basin would have served as a vantage point from which people could watch out for predators like tigers. Second, because the site was a more open environment in a wooded area, it would have provided sufficient space for people to butcher the animal carcasses. Large boulders and outcroppings of base rock exposed during the excavation were likely to have been exposed when Tangzigou people were using the site. These rocky surfaces could have been used as food-processing platforms, although later the area gradually filled up with colluvium (G. Chaplin, pers. comm.).

Paleoclimate of Yunnan

The climate of Yunnan has been strongly affected by the southwest (Indian) monsoon while most other areas of China, except Sichuan and Tibet, have been under the effect of the East Asian monsoon (Zhang et al., 2004). Paleoclimatic data from multi-proxy lake sediment analyses of lakes in Yunnan show temperature and precipitation changes, which reflect the intensity of the southwest monsoon. During Marine Isotope Stage (MIS) 2 (ca. 25-10 ka BP), it was cold and arid due to the weaker summer monsoon and the stronger winter monsoon (Zhang et al., 2004; Shen et al., 2005; Morrill et al., 2006; Dearing et al., 2008). Unlike northern and southeastern China, where general warming started after the Last Glacial Maximum (LGM) around 15 ka, southwestern China remained cold and dry until ca. 10 ka without any visible effect of the Younger Dryas (ca. 12-11 ka BP) (Jarvis, 1993). During the early Holocene (ca. 10-8 ka BP) strengthening of the southwest monsoon occurred (Jarvis, 1993; Shen et al., 2005; Morrill et al., 2006; Dearing et al., 2008). Both temperature and

precipitation increased during summer and winter leading to wetter and warmer conditions. The southwest monsoon weakened after 8000 BP and through the rest of the Holocene in response to the gradual decrease in summer insolation (Jarvis, 1993; Shen et al., 2005; Morrill et al., 2006; Dearing et al., 2008).

History of excavation at Tangzigou

The first excavation at Tangzigou was conducted by the Yunnan Provincial Museum and the Baoshan Museum for two weeks in 1987. Numerous bones and artifacts were found including seven human skull fragments, 524 stone and bone tools, and 1991 animal bone fragments (Zhang, 1992). Unfortunately, the proveniences of the bones and artifacts were not recorded and no more information than taxonomic identification is available for the animal bones. Since the first excavation, the site has been excavated twice more in 2003 and 2006 by a Chinese-American collaborative team using a systematic archaeological method. I was the member of the excavation crew during 2006. Three trenches (T1, T3. 3x3 m; T2. 3x6 m) were excavated about 10 cm at a time until bedrock was exposed (Figure 1.2). Once the top compact soil was removed (~25 cm deep), bones and artifacts were found in great concentrations. There was no clear stratigraphic distinction encountered suggesting that the bones and artifacts could be treated as one assemblage that accumulated over a short time period. This inference was supported by the result of Accelerator Mass Spectrometry radiocarbon dating of the carbon samples with good provenience (Peking University Radiocarbon Laboratory. Sample numbers: BA04271-04275). The data confirmed that the site was deposited over a short period of time. The most superficial layer where bones and artifacts were found was dated to 8800 ± 40 cal BP and the deepest layer ~1 m deep from the

surface was dated to 9000 ± 40 cal BP (Figure 1.3). All of the excavated sediments were

meticulously dry- and wet-sieved through 3 mm steel mesh screens. All of the bones were

retrieved and saved for further analysis regardless of the identifiability during the excavations.

Figure 1.2. Tangzigou excavation map. Map scale 1: 500. Contour interval 1 m.
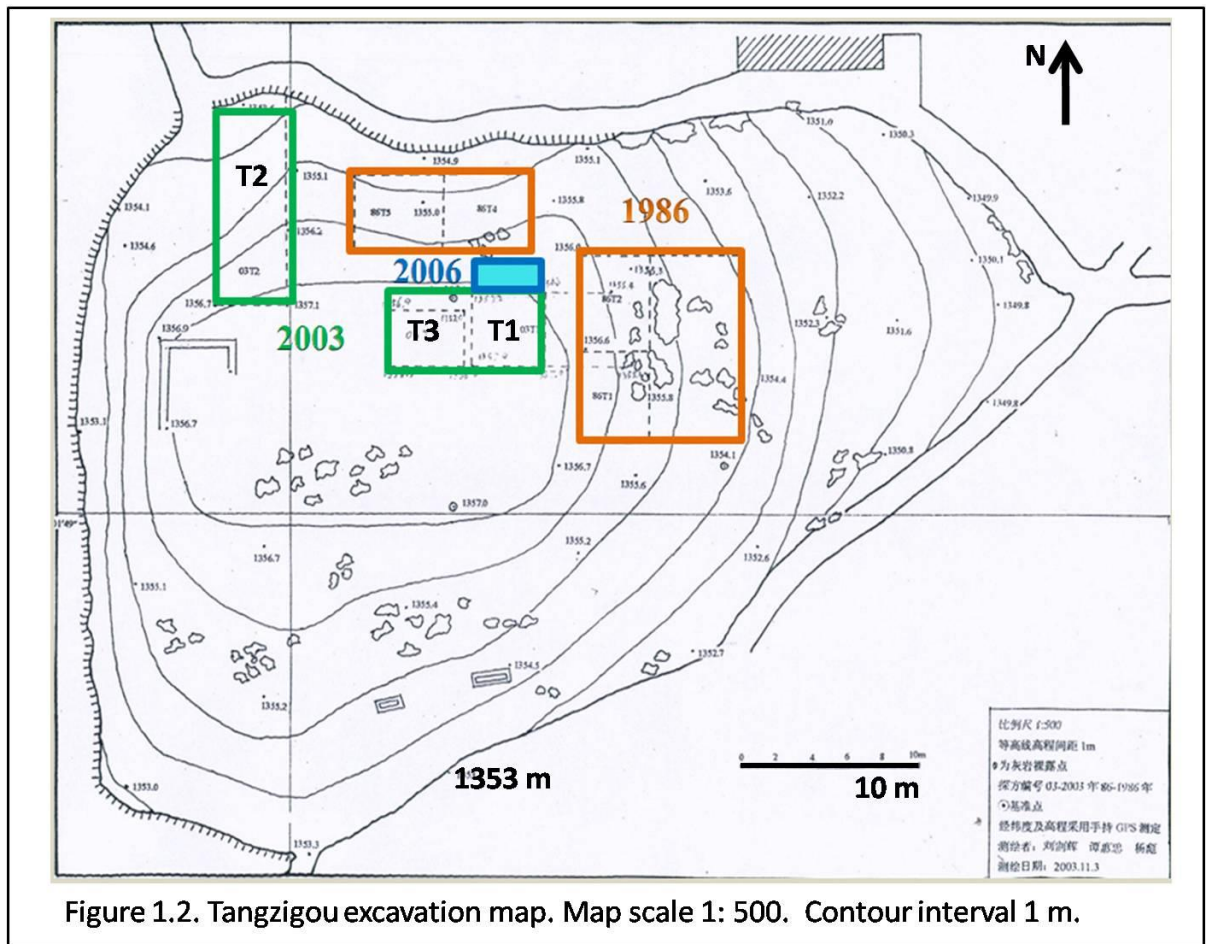
Numerous stone and bone tools were found (Figure 1.4). Stone tools were mostly flaked

tools made from river cobbles. Stone tools are being analyzed by the Paleolithic

archaeologists in Yunnan and are not part of this study. Several ground stone axes were also

discovered. Tangzigou also yielded 26 indisputable and 23 possible bone tools. Most of the

bone artifacts are bone awls and small bone objects with artificial holes. Each of the small

bone artifacts was made from a distal metapodial from a small-sized deer. These metapodial were split in half longitudinally and treated or used in some way that left numerous parallel striations that ran diagonal to the long axis of the bone on the outer surface. An artificial hole was created above the distal trochlea. Five specimens showed this distinctive pattern of modification, leading to the conclusion that this was not a single random event but a patterned methodology for creating a specific tool. I am currently conducting micro-wear studies on these bone tools to document manufacturing technique and possible use-wear.

Although there were several burned bone specimens, no evidence of fire was found at the site nor were there accumulations of fire-cracked rock such as occur at sites where hot stones have been used to boil objects in hide containers (Abbott and Frederick, 1990; Hester, 1991; Hodder and Barfield, 1991). No pottery was discovered. The lack of hearths, fire-cracked stones, and pottery strongly support the interpretation that boiling was not a technique used by Tangzigou people to process animal remains at this site.

Figure 1.3. Stratigraphic profile and chronometric dates from Tangzigou

Figure 1.4. Stone and bone tools from Tangzigou

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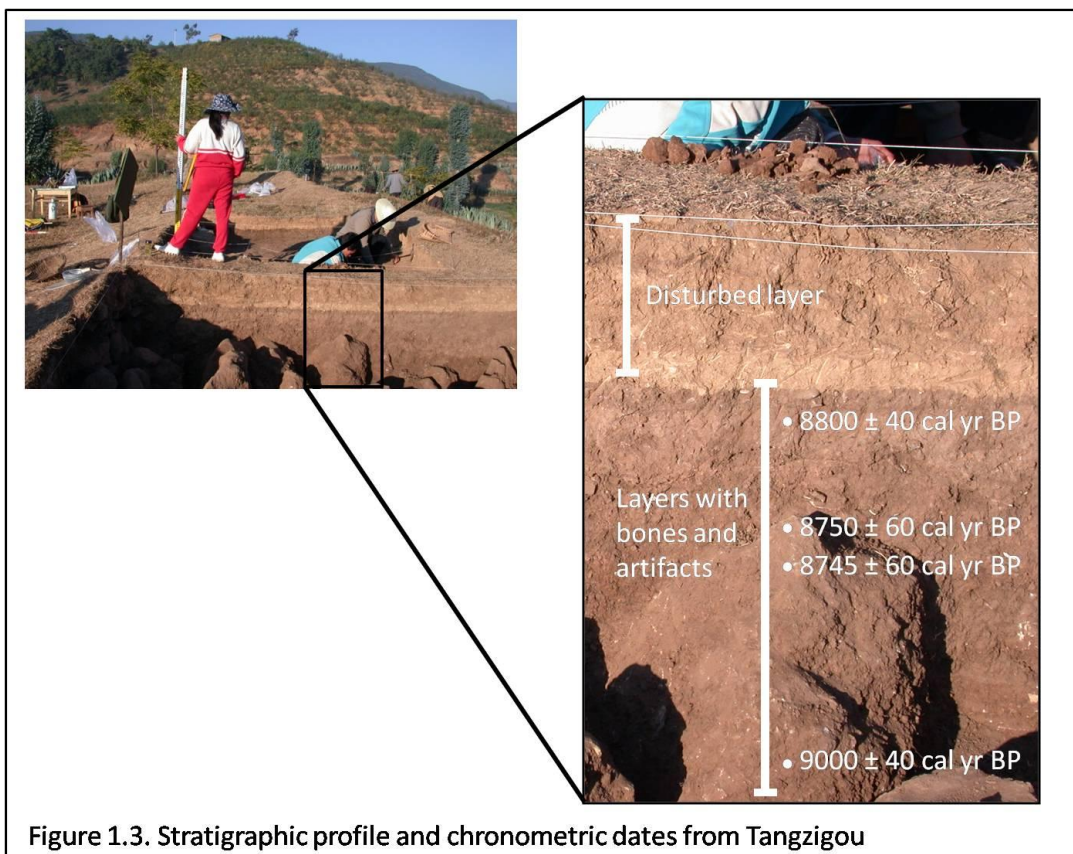
1-2. Significance and limits of this study

The significance of this research is twofold. First, this study is the first rigorous zooarchaeological and taphonomic analysis on the faunal assemblages from Yunnan, and also one of the very few from China. Despite the fact that animals were a crucial part of the prehistoric human diet, the current understanding of the subsistence pattern in post-Pleistocene China is based primarily on the plant remains from eastern China (Zhao and Piperno, 2000; Crawford, 2006; Hu et al., 2006; Zong et al., 2007; Lu et al., 2009). Although the situation is changing (e.g., Ma, 2003; Norton, 2007a; Lam et al., 2010; Yuan, n.d.), animal bones receive very little attention in the Chinese archaeological studies beyond species identification. Analyzing animal bones (zooarchaeology) and how they were transported and buried at the site (taphonomy) is essential in understanding human foraging behavior (Lam et al., 2010). Zooarchaeological and taphonomic analysis, such as the methods used in the current study, will not only add valuable new perspectives to our knowledge of resource utilization patterns during the Early Holocene but will also produce a detailed, quantitative dataset that will facilitate further inter-site and diachronic comparative studies.

Second, this study provides large-scale comparative datasets of actualistic information about modern antlers and modern cervid/bovid phalanges that can be used in further archaeofaunal analyses. Antlers and phalanges were frequently utilized by prehistoric people as tools and food resources (e.g., Guilday et al., 1962; Pokines, 1998; Riedel et al., 2004; Bar-Yosef, 2007). In addition, these are durable materials that tend to be well preserved in faunal assemblages. However, little has been done to document natural vs. human-made surface

modifications and breakage patterns of antlers and phalanges. Such documentation is crucial if analysts are to be able to reliably distinguish between human and non-human made modifications. This distinction is in turn a prerequisite to drawing reliable behavioral inferences about human activities from a faunal assemblage.

I do not attempt to draw a conclusion on the larger scale subsistence pattern change based on the analysis of a single faunal assemblage from one site in China. My focus is to investigate whether there were signs of resource intensification at Tangzigou during the time of site formation using the theoretical and analytical frameworks that have been applied to the previous studies from other parts of the world (e.g., Munro and Bar-Oz, 2005; Bar-Oz and Munro, 2007; Hill, 2008; Norton and Gao, 2008a; Prendergast et al., 2009) and supplementing them with new information from my own actualistic studies. The conclusion of this study will be limited in scope until more quantitative analysis from the archaeological sites in East and Southeast Asia becomes available for further comparisons. Only then, will we be able to understand the detailed picture of the subsistence shift during the Pleistocene-Holocene transition in southern China. By producing a detailed, analytical, and quantitative analysis of the Tangzigou assemblage, informed by new observations and experiments, I hope to take a significant step toward that larger goal.

1-3. Chapter Summary

This dissertation has five chapters. The first chapter outlines the goal of this study and provides an introduction to the Tangzigou site. The next consecutive three chapters are

stand-alone papers written in a scientific journal article format that have been published or are being prepared for publication.

Chapter two is a comprehensive analysis of the Tangzigou faunal assemblage that forms the basis of the remaining chapters. I analyzed the skeletal element representation, mortality profile, bone breakage and surface modification patterns to reconstruct the Tangzigou subsistence pattern such as carcass treatment and transportation decisions. These data are then compared to the results from actualistic studies and analysis of the archaeofauna in the Levant and south China to understand the broader meaning of the Tangzigou subsistence pattern. (This chapter is referred as "Jin, 2010" in the next two chapters.)

Chapter three is devoted to the cervid and bovid phalanges from Tangzigou. Broken phalanges from archaeological sites are usually considered to be evidence of resource stress due to their low nutritional utility. Although the analysis of the bone breakage pattern of other skeletal elements from Tangzigou (in Chapter two) provided no evidence of resource stress or intensive carcass processing at Tangzigou, the foot bones were intensively processed, probably for marrow, which is often considered a signature of resource intensification. In order to understand this seemingly contradictory dataset, I conducted experimental studies with 142 modern cow and deer phalanges. The results are then combined with ethnographic data to argue that broken phalanges by themselves cannot be taken as evidence of resource stress.

In Chapter four, I specifically focused on the antler tools from Tangzigou in order to examine whether the purported antler tools from archaeological sites, including Tangzigou, are really human-made tools. Because natural deer behavior can leave various modifications on antlers, documenting these natural wear features is a crucial first step in identifying antler tools from archaeological sites. In order to produce a comparative dataset, I examined 347 white-tailed deer antlers to document the types and frequencies of natural modifications. This chapter has been published in *Quaternary International* (2010), volume 211, pp. 91-102 as "Jin, J., Shipman, P., Documenting natural wear on antlers: A first step in identifying use-wear on purported antler tools."

In the summary and conclusions (Chapter five), I combine the results of the previous three chapters to discuss the human subsistence pattern at Tangzigou.

Chapter 2

Zooarchaeological and taphonomic analysis of the faunal assemblage from Tangzigou: any evidence of resource intensification?

Authors: Jin, J., Jablonski, N., Hesse, B., and Ji, X.

2-1. Introduction

The nature of the transition from a mobile, foraging-based to a sedentary, agriculturally-based economy is one of the most debated topics in prehistoric research. Archaeological records suggest that this transition started in many parts of the world during the Pleistocene-Holocene boundary. It is especially well documented in the southern Levant (Bar-Yosef and Meadow, 1995; Bar-Yosef, 1998; Zeder, 2008). In East Asia, this transition appears during the Early Holocene in China, and Middle to Late Holocene in other regions (e.g., Korea, Japan). Despite regional differences in the exact timing and detailed sequence of this transition, what is commonly found during this period is the evidence of resource intensification. Therefore, resource intensification is frequently considered the classic archaeological signature of significant subsistence change (Bar-Yosef, 1998; Stiner, 2001; Munro, 2004; Davis, 2005; Norton, 2000, 2007a; Prendergast et al., 2009).

Resource intensification can be defined as "the extraction of increased amounts of energy from a given area at the expense of foraging efficiency" (Munro, 2009: 141). The commonly accepted signs of resource intensification from zooarchaeological assemblages are dietary expansion and intensive carcass processing. Generally known as the "broad spectrum revolution" (Flannery, 1969), increasing dietary breadth can be achieved by adding species that were largely ignored before, e.g., animals with small energy return either due to their

small body sizes or elusive behavior (Stiner, 2001; Steele and Klein, 2009). An alternative strategy from increasing the number of food items could be more intensive processing of individual carcasses to extract more calories from marrow and grease (Munro, 2004; Munro and Bar-Oz, 2005; Steele and Klein, 2009).

China is generally accepted as one of the independent centers of plant domestication where millet and rice cultivation started around 10,000 BP (Crawford, 2006; Hu et al., 2006; Zong et al., 2007; Lu et al., 2009). Although still few, archaeological studies on plant remains found signs for resource intensification, e.g., intensive exploitation of a wider variety of crops, during the terminal Pleistocene as a probable response to increased seasonality (Lu, 1999; Crawford, 2006). In contrast to plant remains, however, animal bones have been largely ignored from archaeological studies. Although this situation is changing (e.g., Yuan and Flad, 2002; Norton and Gao, 2008a, b; Prendergast et al., 2009), analyzing faunal remains (zooarchaeology) and understanding the process of assemblage formation and preservation (taphonomy) are still a relatively young field of research in China (Lam et al., 2010). Of the few such analyses already conducted on Chinese archaeofauna, the majority have been focused on sites in northern and central China along the Yellow and Yangzi River.

In southern China, there are several Late Pleistocene-Early Holocene sites that have yielded pottery, stone/bone tools, and plant/animal remains, such as Yuchanyan (Hunan Province), Xianrendong, Diaotonghuan (Jiangxi Province), and Zengpiyan (Guangxi Province) (Zhang and Hung, 2008; Prendergast et al., 2009 and references therein). Among these sites, the Late Upper Paleolithic cave site Yuchanyan is the only site that has been studied with a

quantitative zooarchaeological and taphonomic method that makes further inter-site comparison possible (Prendergast et al., 2009). Prendergast and her colleagues (2009) found evidence of extensive exploitation of cervid carcasses to maximize nutritional benefits which is a classic sign of resource intensification. Deer bones with higher marrow content showed high degrees of fragmentation while the marrow-poor bones were relatively complete (Prendergast et al., 2009). However, it is difficult to understand the overall subsistence pattern change in southern China with the Yuchanyan fauna alone as Prendergast and her colleagues (2009) pointed out. A broader, a more geographically extensive sample is needed for inter-site and diachronic comparisons from which the bigger picture of the dietary shift in southern China will emerge. Toward this end, we present the results of the zooarchaeological and taphonomic analyses from an early Holocene Tangzigou site in Yunnan Province of southwestern China.

The purpose of this study was to investigate whether there were signs of resource intensification at Tangzigou. This was done by applying a series of taphonomic analyses including study of the skeletal element representation, mortality profile, bone breakage pattern, and bone surface modification. The goal of these analyses was to distinguish human-modified bones from naturally-modified ones (e.g., the effects of carnivore ravaging, density-mediated destruction, and trampling). After the proportion of the assemblage representing human activities was determined, the butchering and transporting strategies of the Tangzigou people were inferred. These results were then compared to other studies from south China and the Epipaleolithic Levant.

2-2. Materials and Methods

The Tangzigou faunal assemblage collected during the 2003 and 2006 field seasons consisted of 5358 identifiable mammal specimens and 3360 unidentifiable fragments. Because the faunal materials from the 1987 excavation could not be located, only the bones from 2003 and 2006 were included in this study. The assemblage is stored in the Yunnan Cultural Relics and Archaeology Institute in Kunming and was studied by the authors between June and August 2008. Although maxillary and mandibular fragments were counted and used in the mortality profile analysis, they were not studied in more detail for species identification.

Cervid and bovid bones dominate the assemblage. Because of the difficulty of distinguishing cervid and bovid postcranial elements at the species level, such specimens were classified into three size classes similar to the one adopted for African bovids by Brain (1981) and for East Asian fauna by Norton and Gao (2008a): Small cervids (<50 kg), large cervids (>150 kg), and large bovids (>600 kg). There were no specimens of small bovid.

Several possible candidate species of cervid and bovid that might be represented by these remains were chosen based on modern biogeography. The post-cranial measurements were taken from the Tangzigou specimens following von den Driesch (1976). These measurements were then compared with the measurements of those candidate species stored in the American Museum of Natural History and the Harvard Museum of Comparative Zoology. The small cervids probably were *Axis porcinus* (hog deer), *Muntiacus* sp. (muntjak), and *Elaphodus* sp. (tufted deer). Interestingly, only 15 specimens of medium cervids were found, thus this group was excluded from the analysis. Large cervids probably

were *Cervus unicolor* (sambar) while large bovids were *Bubalus* sp. (Asian water buffalo) and *Bos* sp. We thus focused our attention on these three size groups: small cervids, large cervids, and large bovids.

Following taphonomic data collection established by Norton (e.g., Norton et al., 2007b; Norton and Gao, 2008a, b), standard zooarchaeological data were collected for each specimen, including taxon, skeletal element, side, and age (Klein and Cruz-Uribe, 1984; Lyman, 1994; Reitz and Wing, 1999). In addition to these, shaft circumference and portion of the shaft (e.g., proximal end with diaphysis, distal near epiphysis) were recorded for the long bones. Then, anatomical landmark data were collected. A separate datasheet was created for each skeletal element (e.g. femur, humerus, and metapodial, etc.) containing anatomical landmarks unique to each of them. The percentage of the preserved anatomical landmark was entered into a database. For instance, if the entire greater trochanter of the femur was present, then it was entered as 1 and if only half of it was present, then entered as 0.5. Minimum Number of Element (MNE) was calculated by adding up these numbers for each anatomical landmark, then choosing the highest number for each skeletal element. Minimum Animal Unit (MAU) and %MAU (bone survivorship) counts were derived following Lyman (1994, 2008). Unidentifiable specimens were tallied and classified into medium (<150 kg) and large mammal (>600 kg) groups. Maximum length was measured for all unidentifiable shafts. Ribs were not counted separately because of two reasons. First, all of them were highly fragmentary without any visible anatomical landmarks. Second, there were only ~ 800 rib fragments in the assemblage indicating that MAU count would be very low and would have little influence on the overall skeletal element profile.

Skeletal element profile

To ascertain the degree of bone density mediated attrition, %MAU values were compared with bone mineral density data derived by Lam et al. (1999) using CT scans. We preferred bone mineral density data published by Lam et al.'s (1999, 2003) over other previously published data (e.g., Lyman, 1994 and references therein) because their method produced the most accurate density values by accounting for the external and internal shape of the bones. The fact that data by Lam et al.'s (1999) were derived for caribou, wildebeest, and horses, i.e., different species from Tangzigou, is not likely to have affected the results because intertaxonomic difference in relative bone mineral density are known to be minimal (Lam et al., 1999; Elkin, 1995). The less dense juvenile bones are generally expected to be more vulnerable to density mediated destruction than the denser adult bones (Marean, 1995; Munson, 2000; Munson and Marean, 2003). Percent MAU for juveniles and adults were calculated separately to test this possibility. Tangzigou %MAU was also compared with the bone survivorship data from a hyena-ravaged assemblage (Marean et al., 1992) to ascertain the carnivore influence on the skeletal element profile.

If the skeletal element profile correlates with the food utility index (FUI), then that might suggest that humans were selectively transporting the bones with high nutritional value. In order to test this hypothesis, the Tangzigou cervid %MAU values were compared with the FUI created by Metcalfe and Jones (1988). Emerson's (1990) Bison Modified Total Products (BMTP) index was used for the Tangzigou large bovid comparison. Binford's (1978) marrow index was correlated with the Tangzigou cervid and bovid %MAU.

Mortality profile

Right mandibles with intact teeth were used to reconstruct the mortality profile. Each specimen was classified into one of the three age categories – juvenile, prime, and old – based on its tooth eruption sequence and the wear stage on the occlusal surface. In order to minimize the intra-observer error, tooth wear was documented twice independently using two different recording criteria which were then reconciled with each other afterwards. The recording system developed by Chapman et al.'s (2005) was used along with the seven-stage criteria we developed (i.e., no wear, light wear, light to medium wear, medium wear, medium to advanced wear, advanced wear, and complete wear). Loose teeth were not included in the mortality profile calculation to minimize the effect of interdependence (i.e., counting two fragments from the same individual twice). Crown height and tooth wear stage were measured and recorded for each loose tooth for further validation of our tooth wear stage recording system. Large bovid was excluded from the mortality profile analysis because of its small sample size (12 intact mandibles).

Tooth wear scores were assigned to one of the following three groups. Juveniles (usually <18 months old) were individuals before sexual maturity that retained deciduous teeth and/or had permanent teeth not fully erupted. Prime and old individuals were distinguished by their permanent premolar and molar wear stage. Prime age group included individuals with slight to moderate wear on M1 and M2 but only slight wear on M3 and permanent premolars. Theoretically this category included individuals from about 18 months to 5 years old based on cervid lifespan data (Grzimek, 1990). Individuals in the old age group had moderate to

heavily worn permanent premolars and molars (Chapman et al., 2005). Modified triangular graphs were used to interpret the mortality profiles. Instead of plotting a single point on the triangular graph to show the percentage of juvenile, prime and old age groups, the modified triangular graph produced a contour showing the 95% confidence intervals of the mortality profile by bootstrapping the age class data for 10,000 times (Steele and Weaver, 2002).

In addition to tooth eruption and wear stage data, the bone fusion sequence was also used to calculate the mortality profile. Although the exact timing of fusion is known to vary across species, sex, and geographic area, no significant variation was found with the fusion sequence of a range of herbivores (Zeder, 2006). Thus, we used available fusion sequence data from sheep, goats, and gazelle (Zeder, 2006; Munro et al., 2009). Bones were grouped into three categories based on the timing of the fusion: 1) early-fusing parts (scapula, distal humerus, proximal radius, acetabulum, first and second phalanges), 2) middle-fusing parts (distal tibia, calcaneus, distal metapodial), and 3) late-fusing parts (distal radius, proximal/distal ulna, proximal/distal femur, proximal tibia, proximal humerus). The mortality profile was created by calculating the percentage of mature specimens (%Mature) in each category. NISP, not MNE, count was used in this calculation because the MNE count showed a strong correlation with the NISP count for each animal size group (small cervid r = 0.833, p <0.01; large cervid r = 0.925, p <0.01; large bovid r = 0.926, p <0.01) as was already known from other assemblages (Lyman, 2008: his table 6.16). Percentage of mature specimens was calculated in two ways to account for the effect of interdependence, that is the likelihood of counting an unfused epiphysis and an unfused shaft from the same individual twice (Hesse and Wapnish, 1985). First, each specimen was counted as a separate

bone, the condition of minimum interdependence. Second, unfused epiphyses and unfused shafts for each skeletal portion were counted separately and the greater value among those two was used as the number of immature specimens, the condition of maximum interdependence.

Bone breakage pattern

For each bone fragment, the breakage pattern was recorded. The fracture angle was recorded as oblique and perpendicular and fracture outline as having curved/V-shaped, perpendicular, and intermediate pattern (Shipman, 1981: p. 105; Villa and Mahieu, 1991). For each long bone shaft, the proportion of the preserved circumference was recorded following Bunn (1983): Type 1 shaft (preserves < 50%), type 2 shaft (between 50% and 100%), and type 3 shaft (complete). For this particular analysis, we used medium and large mammal groups instead of the small and large cervids and large bovids in order to include the unidentifiable shafts. This produced a more accurate picture of fragmentation pattern because small bone chips were difficult to identify to taxon and element but still contained information on bone breakage patterns (Outram, 2001).

Percent completeness (i.e., percentage of the bones represented as a whole) was calculated to see whether marrow-containing bones were more broken than non marrow-containing bones. The MNE of complete bones were divided by the total MNE of the bone. The Completeness Index (CI) was calculated following Marean (1991). He proposed to use the fragmentation ratio of the compact bones with no marrow (astragalus, carpals, tarsals, and sesamoids) at different sites as a measure of post-depositional destruction because these bones are rarely

fragmented by humans and/or carnivores (Marean, 1991). A lower CI suggests a higher degree of post-depositional destruction and vice-versa.

Bone surface modification

Bone surface modification data, such as cut marks, percussion marks, tooth marks, weathering, abrasion, root etching, were recorded (Behrensmeyer, 1978; Shipman, 1981; Capaldo and Blumenschine, 1994; Lyman, 1994). Identification of such marks was made by using a 16x hand lens under strong incandescent light. Surface modification data were also collected from the unidentifiable specimens.

2-3. Results

A wide variety of animal species were identified from Tangzigou (Table 2.1; Zhang, 1992; Ji et al., 2004). Among these taxa, cervids were the most abundant group accounting for 76% (n = 4053) of the total NISP. Small cervids dominated the cervid assemblage (NISP=2836; MNI=73). Large cervids (NISP=1202; MNI=15) and large bovids (NISP=1026; MNI=13) were the next most abundant groups.

Table 2.1. Vertebrate species identified by Zhang et al., 1992

Vertebrate Taxa from Tangzigou	
Taxon	
Mammals	**Birds**
Primate	**Galliformes**
Homo sapiens	Phasianidae
Trachypithecus phayrei	*Phasianus* sp.
Rhinopithecus avunculus	*Phasianus colchicus*
Rhinopithecus sp.	Tetraonidae

Macaca cf. mulatta
Macaca nemestrina
Artiodactyla
  Cervidae
    Muntiacus reevesi
    Muntiacus muntjak
    Muntiacus sp.
    Elaphodus sp.
    Cervus unicolor
  Bovidae
    Bos gaurus
    Bubalus bubalis
  Suidae
    Sus sp.
Perrisodactyla
    Rhinoceros sondaicus
Proboscidea
    Elephas maximus
Carnivora
  Mustelidae
    Martes flavigula
    Arctonyx collaris
    Amblonyx cinerea
  Viverridae
    Paguma larvata
    Viverra zibetha
    Viverricula indica
  Ailuridae
    Ailurus fulgens
  Canidae
    Cuon alpinus
  Felidae
    Panthera pardus
    Panthera sp.
  Ursidae
    Ursus arctos
    Ursus thibetanus
    Ailuropoda melanoleuca
Rodentia
  Sciuridae
    Calosciurus erythraeus
    Callosciurus sp.
    Ratufa bicolor

Perdix sp.
Coturnix coturnix
Bambusicola sp.
Columbiformes
    Columba sp.
    Streptopelia orientalis
Falconiformes
  Falconidae
    Falco cherrug
    Falco subbuteo
  Accipitridae
    Buteo sp.
Piciformes
  Picidae
    Dendrocopos sp.
Passeriformes
  Corvidae
    Corvus sp.
  Muscicapidae
  Turdidae
    Geokichla sp.
    Turdus sp.
Cuculiformes
  Cuculidae
    Cuculus sp.
Charadriiformes
  Scolopacidae
    Tringa sp.

Petaurista albiventer		
cf. Petaurista		
Hylopetes alboniger		
Sciuridae gen. et sp. indet.		
Muridae		
Rattus brunneusculus		
Rattus nitidus		
Rattus rattus		
Rattus sp.		
Niviventer confucianus		
Leopoldamys edwardsi		
Leopoldamys sp.		
Muridae gen. et sp. indet.		
Rhizomyidae		
Rhizomys pruinosus		
Rhizomys sinensis		
Rhizomys sp.		
Hystricidae		
Atherurus macrourus		
Hystrix subcristata		
Hystrix sp.		
Insectivora		
Talpidae		
cf. *Scaptonyx fusicaudus*		
Sociridae		
cf. *Crocidura*		
Anourosorex squamipes		
Scandentia		
Tupaia belangeri		
Tupaia sp. indet.		

Skeletal element profile (Table 2.2-2.4)

There was no significant correlation between bone structural density and %MAU in the three

size groups from Tangzigou. All of the size groups showed insignificant negative correlation

(small cervids, r = -0.294, p = 0.129; large cervids, r = -0.366, p = 0.056; large bovids, r = -

0.070, p = 0.722). No correlation was found between %MAU of the hyena-ravaged sample

and Tangzigou %MAU (small cervids, r = -0.176, p = 0.627; large cervids, r = -0.109, p =

0.763; large bovids, r = -0.079, p = 0.829). No evidence of age-correlated differential

destruction was found in the skeletal element profile of the cervids and bovids (Table 2.4).

In contrast, food utility index (FUI) showed a significant negative correlation with %MAU

for the large cervids (r = -0.459, p = 0.048) and the large bovids (r = -0.530, p = 0.020) but

not with the small cervids (r = 0.362, p = 0.128).

Table 2.2. NISP, MNE, NISP:MNE, MAU, and %MAU of the Tangzigou small cervids, large cervids, and large bovids.

	NISP			MNE			NISP:MNE			MAU			%MAU		
	Small cervids	Large cervids	Large bovids	Small cervids	Large cervids	Large bovids	Small cervids	Large cervids	Large bovids	Small cervids	Large cervids	Large bovids	Small cervids	Large cervids	Large bovids
Antler	52	15	0	*	*	*	*	*	*	*	*	*	*	*	*
Tooth	232	97	84	*	*	*	*	*	*	*	*	*	*	*	*
Maxilla	83	31	6	42.0	17.0	4.0	2.0	1.8	1.5	21	8.5	2	28.7%	55.0%	15.4%
Mandible	185	50	71	62.7	15.7	18.4	3.0	3.2	3.9	31.4	7.9	9.2	42.9%	51.1%	70.9%
Scapula	68	9	15	66.7	5.6	5.9	1.0	1.6	2.5	33.4	2.8	3.0	45.6%	18.1%	22.7%
Humerus Prox	48	5	4	44.1	4.0	4.0	1.1	1.3	1.0	22.05	2	2	30.2%	12.9%	15.4%
Humerus Dist	126	18	19	111.2	10.5	8.9	1.1	1.7	2.1	55.6	5.25	4.45	76.0%	34.0%	34.3%
Radius Prox	89	9	18	81.2	6.0	12.5	1.1	1.5	1.4	40.6	3	6.25	55.5%	19.4%	48.2%
Radius Dist	60	10	11	52.0	8.0	9.5	1.2	1.3	1.2	26	4	4.75	35.6%	25.9%	36.6%
Ulna	41	8	20	39.0	5.3	16.0	1.1	1.5	1.3	19.5	2.6	8.0	26.7%	17.0%	61.7%
Vertebra	359	147	132	201.0	75.0	50.0	1.8	2.0	2.6	7.4	2.8	1.9	10.2%	18.0%	14.3%
Innominate	77	27	14	29.4	7.6	1.5	2.6	3.6	9.3	14.7	3.8	0.8	20.1%	24.6%	6.2%
Femur Prox	105	26	18	93.4	22.5	12.9	1.1	1.2	1.4	46.7	11.3	6.5	63.9%	72.8%	49.7%
Femur Dist	92	23	9	68.7	9.1	3.1	1.3	2.5	2.9	34.4	4.6	1.6	47.0%	29.4%	11.9%
Tibia Prox	54	5	17	46.3	3.1	7.3	1.2	1.6	2.3	23.2	1.6	3.6	31.7%	10.0%	27.9%
Tibia Dist	107	14	17	91.5	10.6	12.1	1.2	1.3	1.4	45.8	5.3	6.1	62.6%	34.3%	46.6%
Astragalus	161	27	33	146.3	22.5	26.0	1.1	1.2	1.3	73.1	11.2	13.0	100.0%	72.7%	100.0%
Calcaneus	101	20	18	77.2	10.1	7.6	1.3	2.0	2.4	38.6	5.1	3.8	52.8%	32.7%	29.1%
Carpal/Tarsal	64	110	126	52.8	99.8	119.4	1.2	1.1	1.1	2.9	5.5	6.6	4.0%	35.6%	50.9%
Metapodial Prox	50	28	38	30.3	12.1	19.4	1.7	2.3	2.0	7.6	3.0	4.9	10.4%	19.6%	37.4%
Metapodial Dist	295	108	53	185.5	61.8	32.1	1.6	1.7	1.7	46.4	15.5	8.0	63.4%	100.0%	61.8%
PH1	139	181	131	88.8	95.5	50.4	1.6	1.9	2.6	11.1	11.9	6.3	15.2%	77.3%	48.5%
PH2	75	125	118	65.5	64.5	55.8	1.1	1.9	2.1	8.2	8.1	7.0	11.2%	52.2%	53.8%
PH3	173	109	54	170.5	94.1	40.7	1.0	1.2	1.3	21.3	11.8	5.1	29.1%	76.1%	39.2%
TOTAL	2836	1202	1026	1846.1	660.3	517.3									

Table 2.3. Test of the effect of density-mediated destruction on the Tangzigou assemblage using bone mineral density data

Skeletal part	Scan site	BMD (Lam et al, 1999)		TZG. MNE			TZG. MAU			TZG. %MAU		
		Caribou	Wildebeest	Small cervids	Large cervids	Large bovids	Small cervids	Large cervids	Large bovids	Small cervids	Large cervids	Large bovids
Mandible	DN3, DN4, DN5	1.06	1.04	62.7	15.7	18.4	31.35	7.85	9.2	42.87%	50.84%	70.88%
Scapula	SP1, SP2	1.25	1.15	66.7	5.6	5.9	33.35	2.8	2.95	45.60%	18.13%	22.73%
Humerus	HU1	0.26	0.32	44.1	4	4	22.05	2	2	30.15%	12.95%	15.41%
	HU3	1.12	1.1	25	5.2	7.4	12.5	2.6	3.7	17.09%	16.84%	28.51%
	HU5	0.48	0.51	111.2	10.5	8.9	55.6	5.25	4.45	76.03%	34.00%	34.28%
Radius	RA1	0.53	0.51	89	9	19	44.5	4.5	9.5	60.85%	29.15%	73.19%
	RA3	1.09	1.07	41.7	6	13.5	20.85	3	6.75	28.51%	19.43%	52.00%
	RA4	0.97	0.96	52	10	9.5	26	5	4.75	35.55%	32.38%	36.59%
Ulna	UL2	0.84	0.85	32	3.25	13	16	1.63	6.5	21.88%	10.56%	50.08%
Innominate	AC1	0.64	0.64	29.4	7.6	1.5	14.7	3.8	0.75	20.10%	24.61%	5.78%
	IL2	1.02	0.96	3.8	0.8	0.3	1.9	0.4	0.15	2.60%	2.59%	1.16%
Femur	FE1	0.39	0.41	93.4	22.5	12.9	46.7	11.25	6.45	63.86%	72.86%	49.69%
	FE4	1.15	1.16	27.9	7	4.5	13.95	3.5	2.25	19.08%	22.67%	17.33%
	FE6	0.32	0.38	68.7	9.1	3.1	34.35	4.55	1.55	46.97%	29.47%	11.94%
Tibia	TI1	0.35	0.42	46.3	3.1	7.25	23.15	1.55	3.63	31.66%	10.04%	27.97%
	TI3	1.13	1.12	33.75	3.95	5.4	16.88	1.98	2.7	23.08%	12.82%	20.80%
	TI5	0.73	0.59	91.5	10.6	12.1	45.75	5.3	6.05	62.56%	34.33%	46.61%
Calcaneus	CA2, CA3	0.73	0.8	77.2	10.1	7.55	38.6	5.05	3.78	52.78%	32.71%	29.12%
Astragalus	AS1, AS2	0.69	0.72	146.3	22.45	25.95	73.13	11.23	12.98	100.00%	72.73%	100.00%
Metapodial	MP1	0.91	0.78	30.3	12.1	19.4	7.58	3.03	4.85	10.37%	19.62%	37.37%
	MP3	1.09	1.15	68.3	25.2	19.2	17.08	6.3	4.8	23.36%	40.80%	36.98%
	MP5	0.45	0.55	184.5	61.75	32.1	46.11	15.44	8.03	63.05%	100.00%	61.86%
PH1	P11	0.48	0.54	88.8	94.5	37.7	11.1	11.81	4.71	15.18%	76.49%	36.29%
	P12	0.56	1.02	53.7	61.5	49.55	6.71	7.69	6.19	9.18%	49.81%	47.69%
	P13	0.71	0.8	39.4	76.2	50.35	4.93	9.53	6.29	6.74%	61.72%	48.46%
PH2	P21	0.61	0.47	65.5	64.5	55.8	8.19	8.06	6.98	11.20%	52.20%	53.78%
	P22	0.72	0.56	27.35	36.8	50	3.42	4.6	6.25	4.68%	29.79%	48.15%
PH3	P31	0.48	0.53	167.7	81	32.4	20.96	10.13	4.05	28.66%	65.61%	31.20%

*For the location of each scan site, see Lyman (1994).

Table 2.4. Spearman's rho correlation results of the Tangzigou %MAU and fragmentation ratio vs. bone mineral density, food utility indices, and carnivore ravaged samples

	Small cervids	Large cervids	Large bovids
Spearman's r bone mineral density vs. %MAU	r= -0.294; p= 0.129	r= -0.366; p= 0.056	r= -0.070; p= 0.722
Spearman's r food value vs. %MAU			
FUI	r= 0.362; p= 0.128	r= -0.459*; p= 0.048	r= -0.530*; p= 0.020
BMTP			r= -0.547*; p= 0.019
Spearman's r marrow index vs. %MAU	r= 0.047; p= 0.852	r= -0.127; p= 0.616	r= -0.065; p= 0.798
Spearman's r marrow index vs. fragmentation ratio	r= 0.154; p= 0.599	r= -0.325; p= 0.257	r= -0.420; p= 0.135
Spearman's r hyena-ravaged %MAU vs. Tangzigou %MAU	r= -0.176; p= 0.627	r= -0.109; p= 0.763	r= -0.079; p= 0.829
Spearman's r bone mineral density vs. %MAU			
Juvenile	r= -0.143; p = 0.640	r= 0.333; p= 0.914	r= 0.074; p= 0.809
Adult	r= 0.110; p= 0.720	r= 0.166; p= 0.588	r= 0.221; p= 0.468
			* denotes statistically significant

Mortality profile (Table 2.5)

Tooth wear stage data derived from the study of Chapman et al. (2005) showed strong significant correlation with the results of our seven-stage method (r = 0.836, p < 0.01). Crown height data also showed significant negative correlation with wear stage (r = -0.63, p < 0.01). These results suggest that intra-observer error was minimal when recording tooth wear stage. The mortality profile based on mandibles showed that the prime age group was the most abundant group in both the small and large cervids (57% and 50%, respectively). Bone fusion-based mortality analysis also generated a prime-age dominated profile.

Table 2.5. Mortality profile of the Tangzigou cervids

Age group	Small cervids	Large cervids
Young	13 (15%)	10 (38%)
Prime	49 (57%)	13 (50%)
Old	24 (28%)	3 (12%)
TOTAL	86	26

Bone breakage pattern

The Tangzigou assemblage was dominated by long bones with mostly curved fracture outlines and oblique fracture angles (71%. n = 341 out of 481). This suggests that the bones were broken while they were still fresh. Percent completeness was low among marrow-containing bones while non-marrow containing bones had a higher % completeness (small cervids: $\chi^2 = 173.8$, df = 1, p < 0.005; large cervids: $\chi^2 = 88.1$, df = 1, p < 0.005; large bovids: $\chi^2 = 22.08$, df = 1, p < 0.005; Table 2.6 and Figure 2.1). For instance, in the small cervid group, % completeness of marrow-containing first (11%) and second (32%) phalanges were low, while those of non-marrow containing astragalus (93%) and third phalanx (96%) were high. Overall the fragmentation ratio (NISP: MNE) was low meaning that bones were not heavily fragmented (Table 2.2). Type 1 shafts were the most abundant type of the total shaft fragments (70%. n = 1858) followed by type 3 (27%. n = 733) and type 2 (3%. n = 95). Completeness Indices (CI) of the Tangzigou compact bones were high (small and large cervids ~91.6%; large bovids ~90.2%; see Table 2.7) suggesting that the post-depositional destruction at Tangzigou was minimal.

Table 2.6. Comparison of % completeness between marrow-containing and non marrow-containing bones from Tangzigou

Small cervids	MNE complete	Total MNE	% Completeness	Yuchanyan	Natufian
Metapodial	0	185.5	0%	*	*
Calcaneus	68	77.2	88%	22%	49.8%
Astragalus	136	146.3	93%	86%	81.6%
PH1	10	88.8	11%	4%	40.2%
PH2	21	65.5	32%	2%	62.3%
PH3	163	170.5	96%	58%	74.6%
Large cervids	MNE complete	Total MNE	% Completeness		
Metapodial	0	61.8	0%		
Calcaneus	5	10.1	50%		
Astragalus	17	22.5	76%		
PH1	6	95.5	6%		
PH2	6	64.5	9%		
PH3	71	94.1	75%		
Large bovids	MNE complete	Total MNE	% Completeness		
Metapodial	0	32.1	0%		
Calcaneus	6	7.6	79%		
Astragalus	19	26.0	73%		
PH1	4	50.4	8%		
PH2	20	55.8	36%		
PH3	23	40.7	57%		

*Natufian data from Bar-Oz and Munro, 2007

*Yuchanyan data from Prendergast et el., 2009

Figure 2.1. Comparison of %completeness between marrow-containing and non marrow-containing bones from Tangzigou
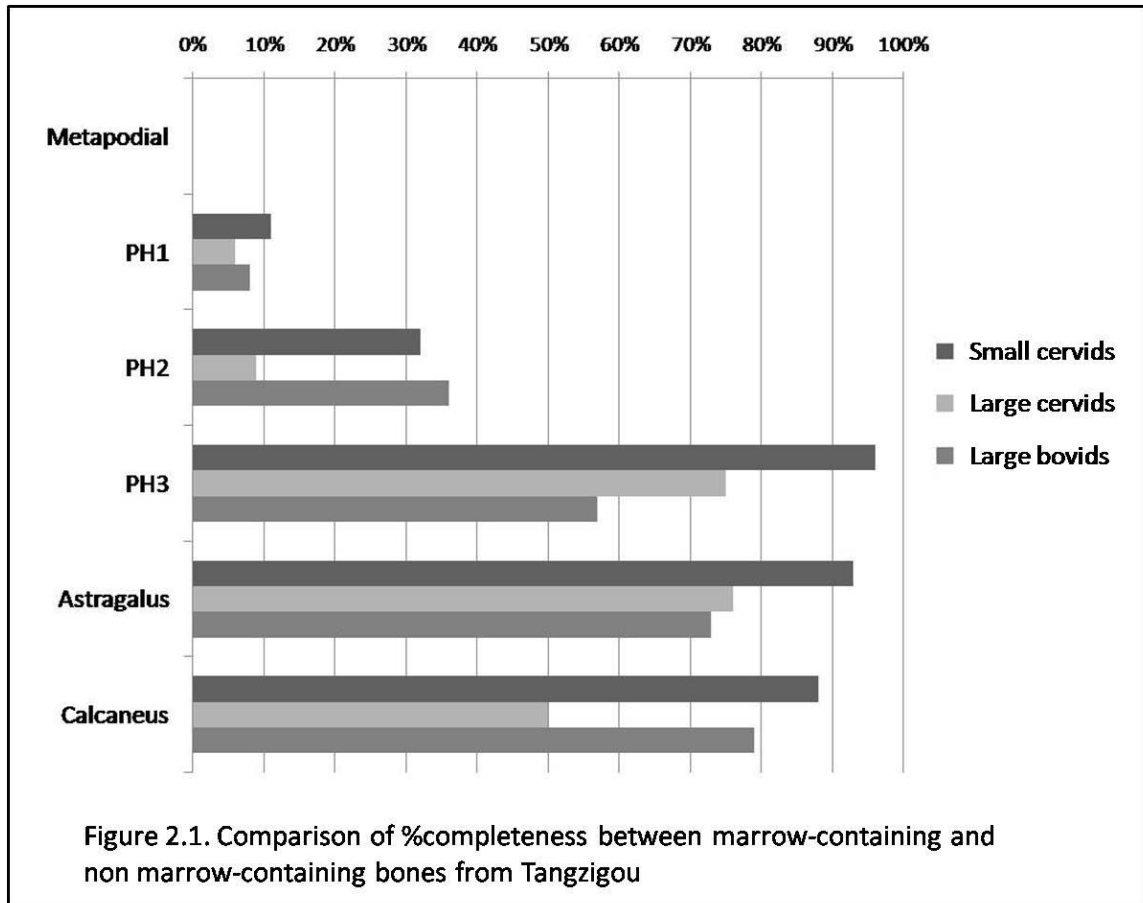
Bone surface modification

Overall, the Tangzigou assemblage displayed very little surface modification. The number of definite cut marks and percussion marks was low. Cut marks were found on 26 specimens and percussion marks were found on 117 specimens (1.6% of the total bone fragments). Carnivore and rodent gnawing marks were found on 60 specimens and 50 specimens showed evidence of weathering and abrasion (1.2% of the total bone fragments).

2-4. Discussion

Quick burial of the assemblage with minimal pre-depositional destruction

Two lines of evidence indicate that the Tangzigou bones were buried quickly after they were brought into the site. First, numerous joints were found still articulated in their anatomical positions and some of them even with the unfused epiphyses "glued" to the diaphyses via matrix (Figure 2.2 and 2.3), showing that little disturbance of their spatial distribution occurred prior to deposition. The abundance of *in situ* articulating elements probably means that connective tissues did not decompose until after the bones were transported to their final deposition (Munson and Marean, 2003). This interpretation is substantiated by observations of modern carcasses. When a carcass is exposed to air in a moderate environment without being disturbed by carnivores and rodents, then the general skeletal shape can be maintained for a couple years (Frison, 1974: 26). However, within three to five months of exposure, the joints and the unfused epiphyses disarticulate and become scattered (G. Milner, pers. comm.; Frison, 1974: 26).

Figure 2.2. Articulated bones from Tangzigou (1). The unfused epiphyses are held together via matrix.

Figure 2.3. Articulated bones from Tangzigou (2). The unfused epiphyses are held together via matrix.

Second, the degree of bone surface modification is minimal suggesting that the bones were not exposed long enough for carnivores, rodents, and other natural agents to modify them in most cases. Large carnivores known in the early to middle Holocene Yunnan were tigers, leopards, and wolves. (It is not clear when domesticated dogs were introduced to this region.) Although none of them crush bones like hyenas, all of these carnivores occasionally gnaw on bones, chew thin bones such as scapula blades and swallow the bones of young animals (Schaller, 1967). Nonetheless, evidence suggestive of those behaviors is rare in the Tangzigou assemblage. Ethnoarchaeological and experimental studies showed that tooth-marked percentages on long bone midshaft fragments were ~ 60% if carnivores had first access over hominins, and ~ 10% if carnivores had access to the meat leftover from hominins (Selvaggio, 1994, 1998; Blumenschine, 1995; Capaldo, 1997, 1998; Lupo and O'Connell, 2002; Norton and Gao, 2008a). In the Tangzigou assemblage, less than 1% of the bones show carnivore tooth marks. Well-preserved long bone epiphyses and the lack of evidence for density-mediated destruction also suggest that carnivore effects on the assemblage were negligible (see below).

Minimal post-depositional destruction

After the bones were buried quickly at Tangzigou, the assemblage could have gone through post-depositional destruction caused by factors such as sediment compaction and soil acidity. High CIs of the Tangzigou compact bones suggested that the degree of post-depositional destruction was negligible. Marean (1991) fed metapodials with compact foot bones still attached to hyenas and then collected the bones immediately after hyenas finished eating to

eliminate post-depositional process. In his experimental studies, 100% of the compact bones were recovered (Marean, 1991). Using these hyena-ravaged assemblages as a reference sample, Marean (1991) compared CIs from two adjacent archaeological sites in Kenya, GvJm46 and GvJm22. The differences in CIs between these two assemblages suggested that GvJm46 had undergone substantially more post-depositional destruction than GvJm22 (Marean, 1991). Tangzigou CIs fell within the range of the sites interpreted as having gone through minimal level of post-depositional destruction such as GvJm22 and Yuchanyan (Figure 2.4 and Table 2.7).

Figure 2.4. Comparison of Completeness Index (CI) from multiple sites
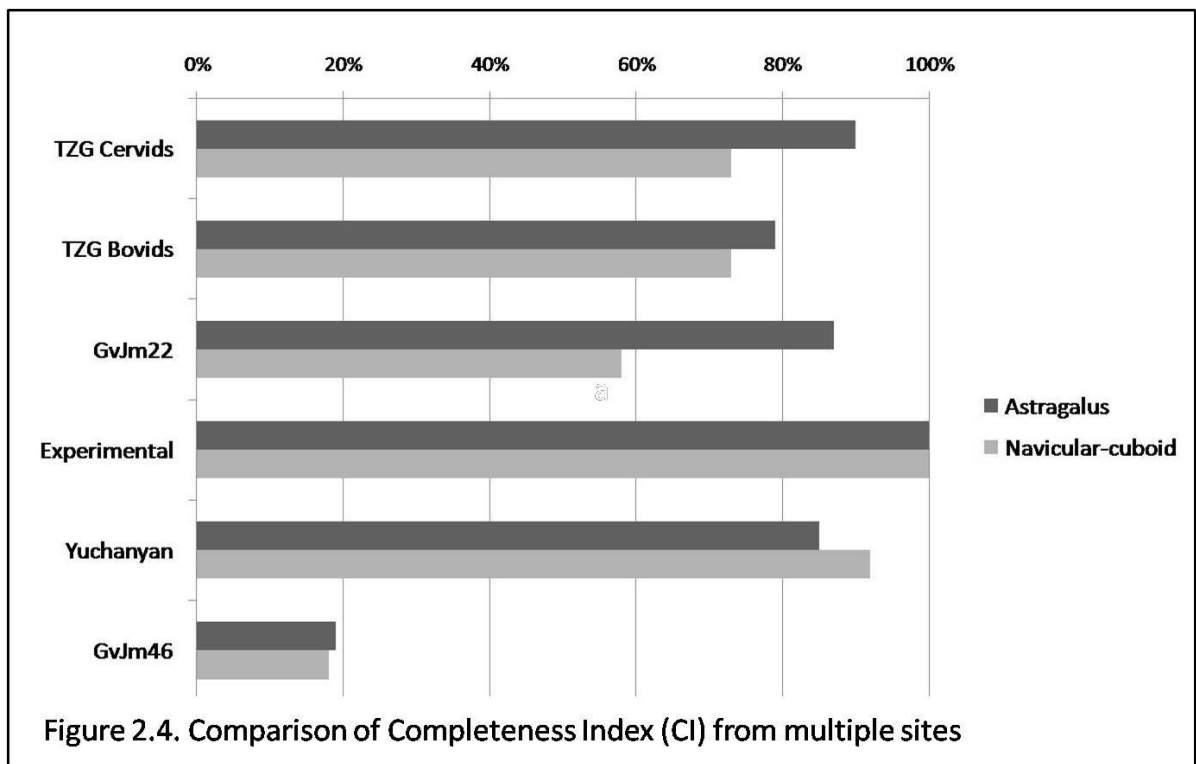
Table 2.7. Comparison of Completeness Index (CI) from multiple sites

	TZG Cervids		TZG Bovids			
	Completeness value/NISP	Completeness Index	Completeness value/NISP	Completeness Index		
Astragalus	172.7/192	90%	25.93/33	79%		
Navicular-cuboid	48.1/66	73%	14.6/20	73%		
Carpal/Tarsal	104.5/108	97%	104.8/106	99%		
Patella	32/32	100%	4.0/4	100%		
Sesamoid	66.8/68	98%	4.0/4	100%		
	TZG Cervids	**TZG Bovids**	**GvJm22**	**Experimental**	**Yuchanyan**	**GvJm46**
Astragalus	90%	79%	87%	100%	85%	19%
Navicular-cuboid	73%	73%	58%	100%	92%	18%
Carpal/Tarsal	97%	99%			100%	
Patella	100%	100%				
Sesamoid	98%	100%				

*GvJm46, GvJm22, and experimental data from Marean (1991)
*Yuchanyan data from Prendergast et al., 2009

Excellent preservation of the small carnivore and bird bones also indicated minimal post-depositional destruction at Tangzigou. If the Tangzigou assemblage went through substantial post-depositional destruction, then the more fragile small vertebrate bones would have been affected first. However, most of the small vertebrate long bones maintained their original shapes without intensive breakage.

No evidence of density-mediated destruction

Density-mediated destruction can happen during both the pre- and post-depositional stages. If bone structural density is correlated with %MAU, then the structurally weaker bones or bone portions, such as long bone epiphysis and vertebra, are underrepresented in the assemblage. During the pre-depositional stage, carnivores and humans can cause this pattern.

Carnivores are known to chew first on the grease-rich long bone epiphysis before the diaphysis (Binford, 1978; Brain, 1981; Marean and Frey, 1997). Humans may destroy the structurally weaker bones when boiling them down for grease (Binford, 1978; Marean and Frey, 1997; Munro and Bar-Oz, 2005). During the post-depositional stage, less dense bones are destroyed in an assemblage more quickly than the denser bones simply due to their structural difference.

No significant correlation between bone structural density and %MAU was found in any of the three size groups from Tangzigou (Table 2.4). This finding indicated that the assemblage was not affected by density-mediated attrition. Tangzigou %MAU did not correlate significantly with %MAU of the hyena-ravaged assemblage studied by Marean and colleagues (1992) suggesting that carnivore ravaging was not a significant factor in the site formation process (Table 2.4).

Because juvenile bones are less dense than adult bones, they are generally likely to be destroyed first (Binford and Bertram, 1977; Marean, 1995; Munson, 2000; Munson and Marean, 2003). If this were the case in Tangzigou, we would expect the juvenile bones to show a high degree of density-mediated attrition. However, the skeletal element profiles of the juveniles in the Tangzigou assemblage did not support this scenario (Table 2.4). Therefore, we can assume that the mortality profile created has not been altered by density-mediated destruction and thus is a relatively accurate reflection of the original mortality profile.

All of the evidence we have examined so far supports the deduction that non-human taphonomic agents had a minimal effect on the formation of the Tangzigou assemblage. Therefore, we evaluated evidence for the role of another possible taphonomic agent that could have played a major role in the assemblage formation, humans.

Differential carcass transportation

There was a significant negative correlation between the food utility index (FUI) and the %MAU for both the large cervids and large bovids (Table 2.4). This negative correlation indicated that these animals were represented in the assemblage by the low-utility body parts. In contrast, the small cervid %MAU was not significantly correlated with the FUI. Animals in this group were roughly equally represented by all body parts (Figure 2.5).

The reverse-utility pattern for large cervids and bovids can be interpreted in several ways. Some assemblages with reverse-utility patterns have been interpreted as a result of methodological error because bone counts were based on the less dense bone epiphyses rather than shafts (Marean and Frey, 1997; Marean and Kim, 1998; Marean et al., 2004). Marean and colleagues argued that failure to include the less identifiable shaft fragments – because only coarse screening was carried out or because of selective retention of the easy-to-identify epiphyses – could produce incorrect skeletal element profile that were an "artifact of method" rather than real phenomena (Marean et al., 2004). Thus any implication about hominin behavior based on these results would be biased and wrong (Marean and Frey, 1997; Marean and Kim, 1998; Marean et al., 2004).

Figure 2.5. Skeletal element representation of the Tangzigou cervids and bovids
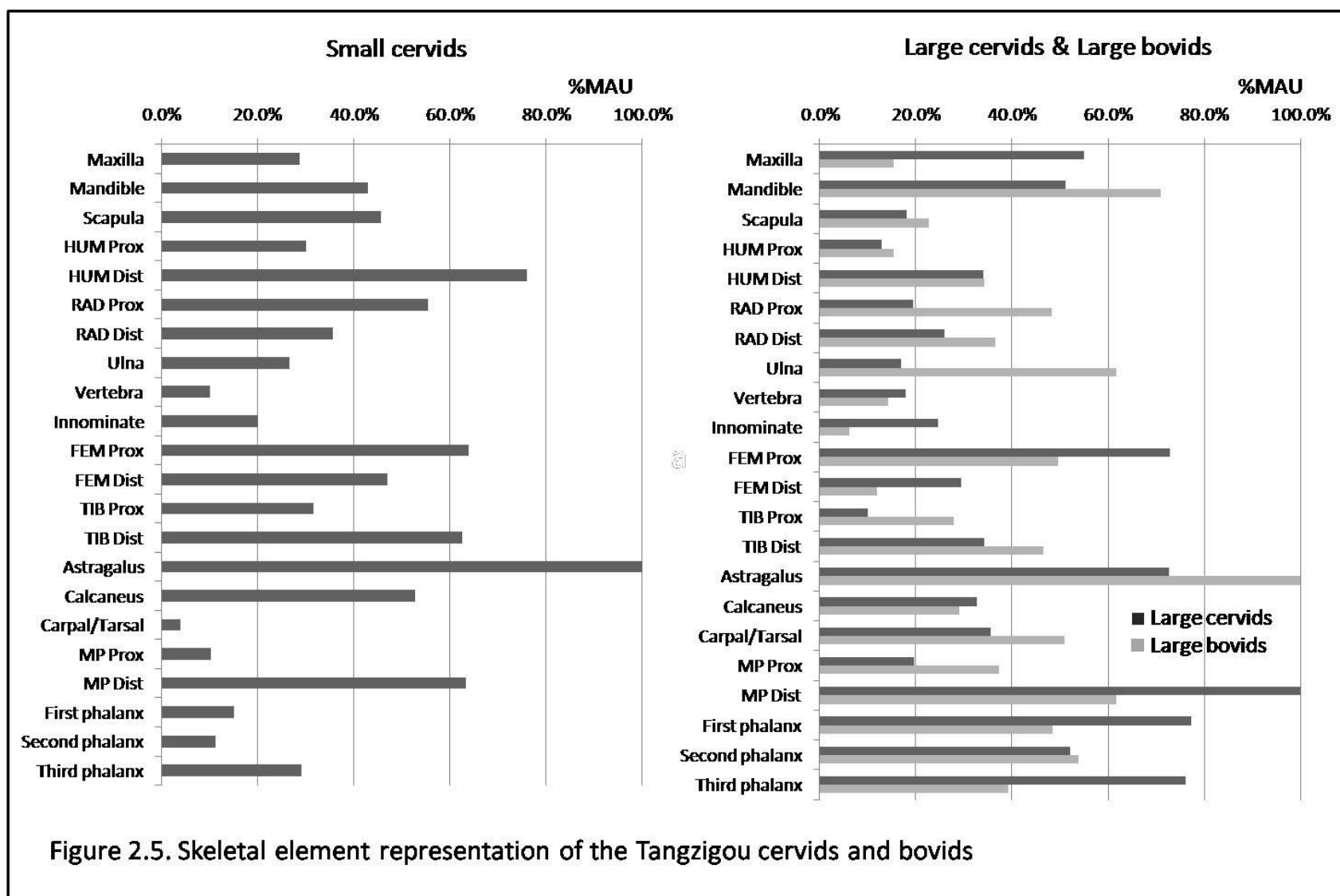
We fully agree with Marean and his colleagues about the importance of including shafts in the analysis. In the case of the Tangzigou assemblage, we do not think that the reverse utility profiles of the large cervids and bovids are methodological artifacts for the following reasons. First, the assemblage was thoroughly sieved through 3 mm mesh screens, ruling out the possibility of coarse screening. Second, all the bone fragments were collected regardless of identifiability, ruling out the possibility of selective retention. Third, all of the "difficult to identify" shafts separated by J. Jin were meticulously double-checked by B. Hesse. This gave us confidence in our identification of the long bone midshafts. Fourth, the reverse-utility pattern was observed in the two larger animal groups but not in the small cervid category, which was collected and analyzed by the same procedures. If the reverse utility profiles of the large cervids and large bovids were an analytical artifact, there is no reason this artifact would be observed only in the larger animals. Thus, the fact that the highest MNE of the long bones were consistently derived from long bone epiphyses not midshafts (see scan sites from Table 2.3) must be a real phenomenon.

The reverse utility pattern can be a by-product of density-mediated destruction because many of the high-utility body parts are structurally weak. Therefore, if the assemblage has undergone density-mediated destruction, then a reverse utility pattern cannot be used to infer human activity. As we discussed above, the evidence for density-mediated attrition is negligible in Tangzigou assemblage. This fact leaves us with the hypothesis that the Tangzigou skeletal element profile was a product of human behavior.

The complexity of analyzing skeletal element profile has been widely appreciated by the

researchers (Lupo, 2001 and references therein). Ethnoarchaeological studies have shown

complex dynamics involved with the hunting and transporting decisions that can produce

various skeletal element profiles including such issues as the number in the hunting groups

and the distance from the base camp (Yellen, 1977a, b; Binford, 1978; O'Connell et al.,

1988). Although it is impossible to understand all such variables that might have affected the

skeletal element profile, we can still infer the most likely behavior included in the formation

of the Tangzigou assemblage.

The Tangzigou skeletal element profile is not unique. The head-and-foot pattern is

widespread in animals with larger body size (e.g., eland and buffalo) but much rarer among

small animals (e.g., sheep and goat) (Klein and Cruz-Uribe, 1998). The most parsimonious

explanation for this pattern is that animal body size affected the human hunting and

transportation decisions. The widespread occurrence of reverse-utility patterns in

assemblages from caves and rockshelters has puzzled researchers because they are more

likely to have been residential sites than kill/butchery sites where a non-reverse utility curve

would be expected (Marean and Frey, 1997).

Unlike those sites, Tangzigou is an open-air site and there is no logical ground to assume that

it was either a kill/butchery site or a residential site. The skeletal element profile of the

Tangzigou assemblage suggests that it was a kill/butchery site. The abundance of head and

foot elements of the large cervids and bovids at Tangzigou suggests either that the meatier

parts were transported away from the site to another place or that humans had access only to

the less meaty parts perhaps through scavenging. Although possible, scavenging by humans is unlikely to have been a major factor at Tangzigou because humans in East Asia have been proficient hunters since at least the latter part of the Early Paleolithic (Norton and Gao, 2008a). The mortality profile analysis also supports the hunting hypothesis (see below). In contrast, small cervid bones were brought in and out of the site regardless of the nutritional value of their attached soft parts, probably due to the relative ease of transport.

Prime-age dominated mortality profile

1) Validation of the age-at-death estimation methods

The mortality profiles based on bone fusion sequences can be used as a complement to those based on tooth eruption sequences and wear stages. Two different counting methods, assuming minimum vs. maximum interdependence, produced almost identical mortality profiles in this assemblage (small cervids, $\chi^2 = 0.061$, df = 2; large cervids, $\chi^2 = 0.046$, df = 2 ; large bovids, $\chi^2 = 0.089$, df = 2; also see Table 2.8). While teeth continuously wear throughout an individual's lifespan, bones do not provide further information about the age once epiphyses are all fused (after 30-48 months). This means that bone fusion is not a suitable method to distinguish prime- from the old-aged animals. Thus, we will focus on the juvenile and prime-aged groups. The juveniles tooth-based mortality profile corresponded to the individuals that died before the early-fusing bones fused (< 18 months). Interestingly, the percentage of animals in this category was much lower when calculated with the bone fusion data, i.e., dental age yielded a younger age profile than the fusion data (Table 2.5 and 2.8).

There are several possible explanations for this disparity. First, the rate of tooth eruption and wear for the cervids at Tangzigou could have been slower than those of the muntjacs used in the study of Chapman et al. (2005). Although the muntjac is one of the candidate species for the small cervid at Tangzigou, the muntjacs from England used in the study of Chapman et al. (2005) may have had different tooth eruption and wear rates because of differences in feeding ecology. Second, the long bones of the Tangzigou cervids might fuse earlier than sheep, goats, and gazelle (Zeder, 2006; Munro et al., 2009). Third, juvenile mandibles might be preserved better in the assemblage than juvenile long bones. This scenario is unlikely given the excellent bone preservation at Tangzigou and the lack of correlation between the juvenile skeletal element abundance and bone mineral density. No matter what the source of the disparity between the mortality estimates based on dental and bone fusion, it does not alter the interpretation of the Tangzigou cervid mortality profile. Decreasing the number of juveniles with the fusion data will not affect the already prime-dominated mortality profile of the small cervids created with the dental data.

2) Interpretation of the Tangzigou mortality profile

Analyses of mortality profile of the archaeofaunal assemblages can be informative of prehistoric human foraging behavior. There are two basic forms of mortality patterns in the mammalian community: "living" and attritional mortality patterns (Figure 2.6; Klein, 1982; Stiner, 1990). The living mortality pattern resembles the age structure of an actual living population *at a given time* with a decrease in the number of individuals in each successively older age group (Lyman, 1989). It is a snapshot of the age structure of a live population. The living-structure mortality pattern can result from 1) catastrophic events, such as volcanic

eruption and large-scale floods, and/or 2) accumulation of animal carcasses by ambush hunters (including humans) who were capable of taking prey from all age categories (Stiner, 1990).

Attritional mortality pattern reflects the mortality structure of a living population *throughout the time* with a high number of the more vulnerable individuals, i.e., the young and old age groups (Lyman, 1989). This is the most commonly observed death pattern in nature (Stiner, 1990). Attritional mortality pattern can result from 1) the predators (including humans) primarily preying on the very young and aged individuals, and/or 2) diseases and accidents targeting the more vulnerable age groups. Although the old group has a high mortality risk, the number of individuals in this group is not high in a death assemblage due to the smaller number of individuals who live to reach that age group.

The mortality profile analysis of the eland and Cape buffalo from Klasies River Mouth cave 1 in South Africa (128,000-74,000 years old) provides an example of the human foraging behavior (Klein, 1978). The eland remains produced a living-structure mortality pattern, indicating that prehistoric people hunted elands of all ages. In contrast, Cape buffalo was represented by a high number of juveniles and significantly lower number of all other age groups, producing an attritional mortality profile. Klein (1978) argued that the difference in the mortality profile of the preys is likely due to the behavioral difference of the eland and Cape buffalo. The Middle Stone Age hunters were capable of hunting the docile elands of all age, while it was more challenging to hunt a prime-aged Cape buffalo due to its aggressive defense behavior, making the hunters to target the juveniles.

The Tangzigou mortality profiles of both small and large cervids produced a living structure with the prime-aged being the most abundant group (Table 2.5; Figure 2.6). However, the mortality pattern of the large cervids is inconclusive. The 95 % contour line of the large cervids on the modified triangular graph (Figure 2.6) lies between living and attritional age structure. This means that, statistically speaking, the large cervids mortality pattern can represent either a living or attritional population or something intermediate. This is likely due to the smaller sample size of the large cervid group which increased the 95% contour line area to approximately twice the size to that of the small cervid group. Therefore, the large cervid mortality profile cannot be used to draw any further inference on hunting behavioral strategy. The small cervids from Tangzigou produced a living-structure death pattern. The absence of evidence for natural disaster or significant carnivore activities at Tangzigou indicates that humans produced the mortality profile showing that they were able to take individuals from all age groups focusing on prime-aged animals. It is probably because of the higher caloric return yield of the prime-aged animals compared to the young or aged ones.

When humans exploit an environmental resource more intensively, the percentage of juveniles in the assemblage should be unusually high (>30 % of juveniles: Munro, 2004; Davis, 2005). This age shift is due to heavy predation pressure that leaves insufficient time for the prey population to recover a normal age profile (Davis, 2005). Several examples of this trend have been found in the southern Levant and North America (Elder, 1965; Davis, 2005). Compared to other sites with evidence of resource intensification, the Tangzigou assemblage has a lower percentage of juveniles (15% for small cervids; see Table 2.5),

suggesting that the Tangzigou people were not applying high predation pressure to the local

prey population (Davis, 2005). This interpretation cannot be confirmed or refuted until other

assemblages from comparable localities are compared.

Table 2.8. Bone fusion sequence based Tangzigou mortality profile

NISP counts. Minimum interdependence.

	Small cervids				Large cervids				Large bovids			
	Immature	Mature	Total	%Mature	Immature	Mature	Total	%Mature	Immature	Mature	Total	%Mature
Early fusing	27	425	452	94.03	43	161	204	78.92	32	146	178	82.02
Middle fusing	133	377	510	73.92	68	60	128	46.88	21	50	71	70.42
Late fusing	95	249	344	72.38	27	26	53	49.06	21	19	40	47.50

NISP counts. Maximum interdependence.

	Small cervids				Large cervids				Large bovids			
	Immature	Mature	Total	%Mature	Immature	Mature	Total	%Mature	Immature	Mature	Total	%Mature
Early fusing	21	425	446	95.29	32	161	193	83.42	20	146	166	87.95
Middle fusing	104	377	481	78.38	55	60	115	52.17	19	50	69	72.46
Late fusing	75	249	324	76.85	24	26	50	52.00	17	19	36	52.78
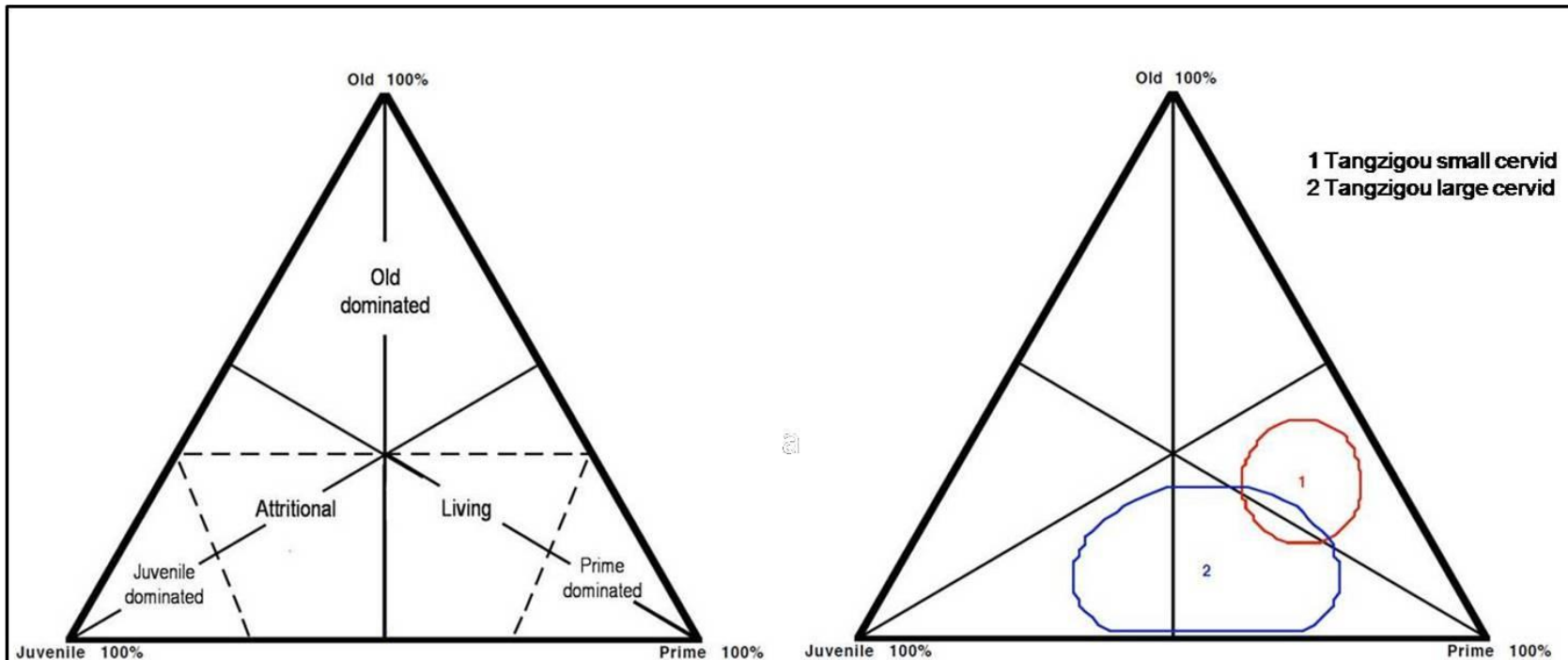
Figure 2.6. Mortality profile plotted on triangular graphs. (Left) mammalian mortality profile. After Stiner (1990); (Right) Tangzigou mortality profile on modified triangular graph. The circles are the 95 % density contours for Tangzigou small and large cervid groups. Courtesy of Tim Weaver and Teresa Steele.

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Dominance of fresh (green) bone breakage: low % completeness and low fragmentation ratio

Bone marrow from long bones has been an important nutritional resource for humans worldwide (Binford, 1978, 1981; Stiner, 1994; Outram, 2001; Munro and Bar-Oz, 2005). Marrow can be extracted by breaking the bones. Thus, fragmentation data can shed light on the marrow extraction behavior. We focused on four aspects of breakage patterns: fracture outline and angle; extent of fragmentation; intensity of fragmentation; and shaft breakage type.

The Tangzigou assemblage is dominated by long bones which were broken while they were still fresh. Even though various non-human taphonomic forces can also produce green breakages, we argue that humans are the most likely candidate for the Tangzigou green bone fractures because various types of taphonomic evidence suggest minimal pre- and post-depositional destruction by non-human agents (see above).

Percent completeness of the bones is a measure of the extent of fragmentation. If there is a significant difference in % completeness between marrow-containing and non marrow-containing bones, then that can be interpreted as an evidence of people extracting marrow. We focused on the lower limb that consists of both marrow-bearing (calcaneus, metapodials, first and second phalanges) and non marrow-bearing (astragalus and third phalanx) bones. In the Tangzigou assemblage, bones with higher marrow yields were more broken than the bones with lower marrow yields. For instance, no single metapodial was complete while more than 70% of the astragali were (Figure 2.1 and Table 2.6). A similar pattern was found

in the Yuchanyan and Natufian assemblages and was interpreted as evidence of marrow extraction (Table 2.6; Bar-Oz and Munro, 2007; Prendergast et al., 2009).

If bones with higher marrow yield are processed more extensively, this behavior will increase the fragmentation ratio (NISP: MNE) (Bar-Oz and Munro, 2007). Despite the clear difference in the % completeness of the marrow-bearing and non marrow-bearing bones at Tangzigou, the intensity of fragmentation did not correlate significantly with the marrow yield (small cervids, $r = 0.154$, $p = 0.599$; large cervids, $r = -0.325$, $p = 0.257$; large bovids, $r = -0.420$, $p = 0.135$). Logically, people under high subsistence stress should process every bit of the within-bone nutrient, thus producing a highly fragmented bone assemblage (Outram, 2001). However, there is no reason to assume that high subsistence stress is indicated whenever we see evidence of marrow extraction. The low fragmentation ratio at Tangzigou might be related to a lack of grease processing.

Bones do not have to be intensively fragmented in order to have their marrow extracted, but need to be highly fragmented in order to be boiled down for grease (Outram, 2001; Wolverton et al., 2008). Analysis of the faunal assemblages from Western European Mesolithic sites showed that earlier pre-ceramic sites generally retained epiphyses of the long bones with a significant portion of the diaphyses still attached and a scarcity of shaft fragments. In contrast, post-ceramic sites yielded a large number of fragments with destroyed epiphyses (Noe-Nygaard, 1977). The same pattern has been found from the mid- to late Holocene pre- and post-pottery sites in Texas (Wolverton et al., 2008). In short, without pottery, fragmenting bones and boiling them for marrow is unlikely to be practiced.

In China, the earliest evidence for pottery comes from Yuchanyan in the south, a site that

dates to 17,700-13,800 cal yr BP (Boaretto et al., 2009). Taphonomic examination of

archaeofauna and evidence for fire suggested that Yuchanyan people might have boiled down

cancellous bones to extract grease (Prendergast et al., 2009). However, there is no evidence

of pottery and fire at Tangzigou, suggesting that grease extracting was not part of the

activities that affected the assemblage. Though pottery is known from older Chinese sites

than Tangzigou, geographic factors discussed above have partially isolated the Tangzigou

area from the rest of China. It is probable that pottery came later to Tangzigou than to other

areas of China, which means that boiling for grease extraction may have also arrived later at

Tangzigou. Although heated stones could have been used to boil objects in hide containers

(Abbott and Frederick, 1990; Hester, 1991; Hodder and Barfield, 1991), there were no

accumulations of fire-cracked rocks from the site.

Ethnoarchaeological and experimental studies showed that if humans were accessing marrow

by cracking the bones with hammerstones, the assemblage should be dominated by highly

fragmented bones and type 1 shafts (Bunn, 1983; Marean et al., 2004). Villa and Mahieu

(1991) showed that shaft circumference could also be used to identify the cause of bone

breakage. High frequencies of complete shaft diameters (type 3) characterize post-

depositional breakage while high frequencies of type 1 indicate fracturing by humans (Villa

and Mahieu, 1991). The dominance of type 1 shafts at Tangzigou (70 %) probably reflects

the production of many bone chips when the bones were broken for marrow. Breaking the

long bones by hitting on the midshaft would have produced numerous identifiable and

unidentifiable bone fragments which were all included in the shaft type count. The length of

the unidentifiable bone fragments suggests that this might have been the case. Ninety-five

percent (n = 634) of the unidentifiable medium mammal fragments were smaller than 3 cm

and 93% (n = 340) of the unidentifiable large mammal fragments were smaller than 5 cm.

The Tangzigou assemblage appears similar to other human-created assemblages because of

the dominance of type 1 shafts. Interestingly, chi-square analyses show that the frequency of

different shaft types in the Tangzigou assemblage is not similar to that from any of the

previously published studies. For example, Tangzigou shaft type frequency is significantly

different from samples created by hammerstone experiments (χ^2 = 217.97, df = 2; Marean et

al., 2004), cannibalism (χ^2 = 66.99, df = 2; Fontbrégoua assemblage from Villa and Mahieu,

1991), marrow extraction (χ^2 = 63.24, df = 2; Prendergast et al., 2009), collection bias (χ^2 =

78.68, df = 2; Bisitun collection from Marean et al., 2004), and post-depositional destruction

(χ^2 = 369.09, df = 2; Sarrians assemblage from Villa and Mahieu, 1991). The differences are

due to the relatively higher percentage of type 3 shafts in the Tangzigou assemblage

compared to other human-created assemblages.

Potentially a carnivore-ravaged assemblage preserves bones with a larger portion of the shaft

thus high number of type 3 shaft (Bunn, 1983; Villa and Mahieu, 1991). In such a case,

carnivore ravaged is diagnosed either by shafts lacking epiphyses or by complete shafts

attached to the epiphyses with carnivore tooth marks appearing on more than 50% of the

sample (Bunn, 1983). Neither diagnostic criterion was observed in the Tangzigou

assemblage, which effectively eliminates the possibility that carnivore ravaging was a major taphonomic factor in the bone breakage type at Tangzigou.

We need now to deduce the most plausible explanation for the Tangzigou bone breakage pattern, i.e., the pattern of the marrow-bearing bones having been mostly broken but with epiphyses well preserved. The Tangzigou pattern could reflect the situation described by Marean and his colleagues (2004: 82) as one "in which a faunal assemblage underwent so little density-mediated destruction that virtually no limb bone ends were deleted." Although such conditions are unlikely for sites that are hundreds of thousands or millions of years old (Marean et al., 2004), it is a condition not unlikely at Tangzigou given its younger age (8800 BP) and excellent preservation. To summarize, humans at Tangzigou broke bones to access marrow by hitting the midshaft. This produced numerous bone chips and splinters but left the bone epiphyses largely untouched. Shortly after being discarded, the bones were buried quickly via colluvial action, so that a significant portion of the original assemblage and the anatomical associations among its bones were preserved.

Consistent pattern of bone breakage

One of the interesting patterns from Tangzigou is the consistent bone breakage patterns observed in first and second phalanges and radius. Intriguingly, first and second phalanges showed different breakage patterns based on the animal's body size. The majority of the large bovid first and second phalanges (69%) were longitudinally split while the small and large cervid ones were transversely split (Figure 2.7). Longitudinally split large bovid phalanges generally retained their whole length (i.e., proximal and distal ends and the entire

shaft is preserved) and were broken along the midline longitudinal axis of the bone. The

fracture outlines were very clear with a smooth fracture edge. Although bones can be broken

in a certain way due to their structural properties, longitudinally split first and second

phalanges of large bovids have not been reported in assemblages untouched by humans. The

fact that 69% of the total phalanges were broken in an almost identical and unusual way is

strongly indicative of systematic butchering behavior by humans.

Figure 2.7. Split phalanges from Tangzigou. A: large bovid PH1. B, C: large bovid PH2.
D, E: large cervid PH1.
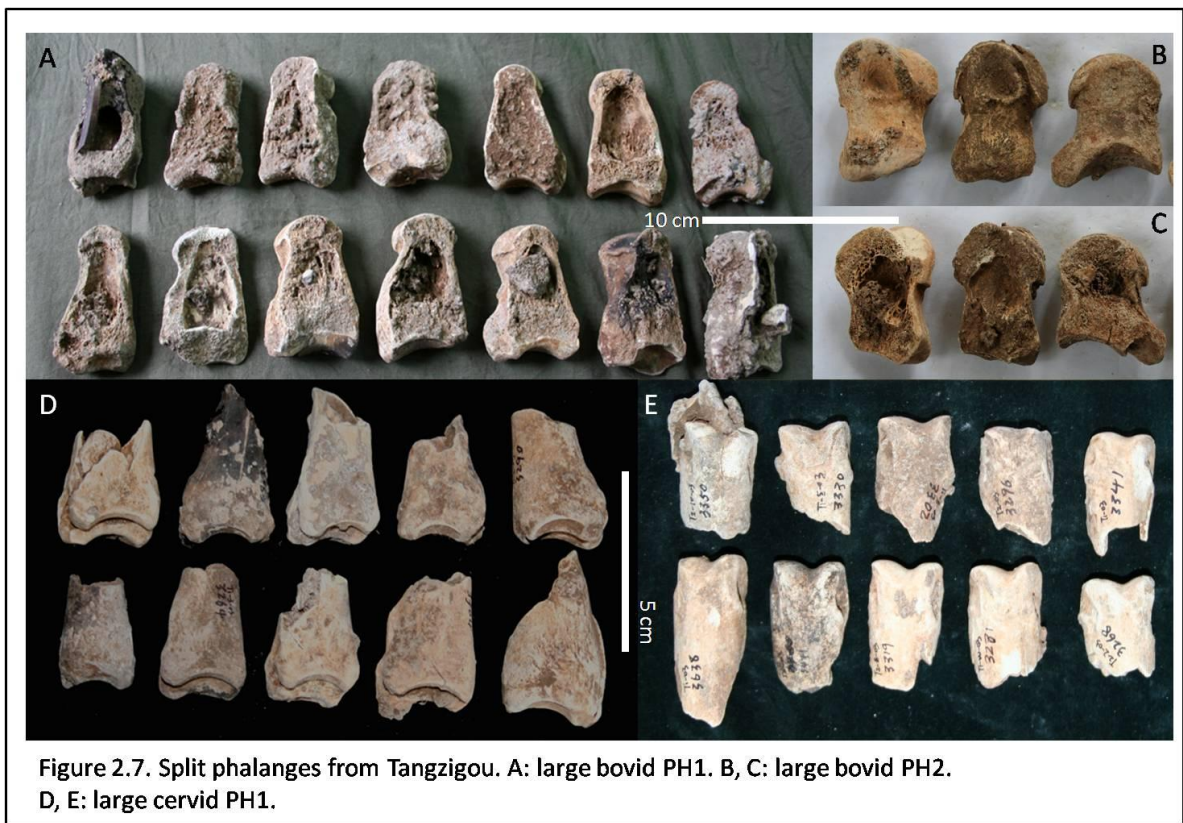
Broken phalanges are not common in archaeological fauna but, if found, they are generally

interpreted in two ways. First, they can provide information on seasonality. The phalanges

of deer and aurochs from a Late Middle Paleolithic site in Italy were split at almost any angle

with no consistent pattern (Stiner, 1994: 146). This was interpreted as indicating that carcasses were processed during early fall and winter when fat levels in the ungulates were high and therefore even the smaller phalanges must have been worth processing (Stiner, 1994: 146). Second, split phalanges were considered by some to be evidence of scarce resources and extensive utilization of animal carcasses because of their low marrow content compared to other long bones (Munro and Bar-Oz, 2005). This explanation is likely to be valid when multiple lines of evidence indicate humans underwent resource depletion, such as during the Epipaleolithic in the southern Levant (Bar-Oz and Munro, 2007; Stutz et al., 2009).

It is still a subject of further study to see whether the split phalanges from Tangzigou support either hypothesis. In order to understand how and why the Tangzigou people were processing the phalanges in the way they did, it is necessary to first document the marrow content of cervids and large bovid species and also the required force and processing time to break the phalanges. Only a few studies have documented such information (Lupo, 1998; Bar-Oz and Munro, 2007). Experimental studies are currently being carried out by one of us (JJ) to produce comparative dataset to interpret split phalanges from archaeological sites (Jin et al., in preparation).

Among the long bones, the radius showed an interesting breakage pattern. Regardless of the body size, radii were broken in a manner that left a horseshoe-shaped fracture on the anterior surface (Figure 2.8). A similar breakage pattern was found on bison radii from a Paleoindian site in Agate Basin that was interpreted as bone tools used for butchering (Frison and

Stanford, 1982:158). Further studies are warranted to understand this particular breakage pattern on the radius.

Figure 2.8. Horse-shoe shaped breakage pattern on Tangzigou radii. Scale bar = 5 cm.

Low frequency of bone surface modifications

If humans were butchering the animals and cracking the bones for marrow, then one might expect to find cut marks and percussion marks on the bones. This was not the case with the Tangzigou assemblage. The low number of cut marks could be explained as the result of non-intensive processing of the carcasses. If the Tangzigou people did not have to remove

all of the available flesh from the carcass, then there would be less chance for them to leave marks on the bones. Alternatively it might be due to the absence of sharp stone tools that are most likely to leave traces on the bones. Tangzigou stone tools appeared to be very similar to the Hoabinhian assemblage from Southeast Asia and mainly consisted of flaked pebble tools. Most of the stone tools at Tangzigou lacked sharp working edge suggesting that these might not have been efficient tools for butchering. Instead, Tangzigou people could have used bamboo. The possibility of East and Southeast Asian prehistoric people using bamboo has been appreciated for decades (Boriskovskii, 1968, 1978; Pope, 1984, 1989). Unfortunately the "bamboo hypothesis" has been supported only with circumstantial evidence. It is because unlike stones bamboo decays quicker hardly leaving any trace for the archaeologists to detect.

The use of bamboo would have been possible during Tangzigou times. Modern Yunnan has the greatest number of bamboo species and the most abundant natural bamboo forest in the world (Yang et al., 2004). Ethnographic studies from Yunnan show how closely related bamboo is to their everyday life of modern peoples in this region. The majority of clothing, hunting tools, utensils, baskets and furniture are made of bamboo and bamboo shoots are consumed frequently for food and/or medicine (Yang et al., 2004). The habitat preferences of the micromammal species in the past indicate that the Tangzigou area was covered with subtropical forest, including pockets of moist bamboo forest, at the time the assemblage accumulated (L. Flynn, pers. comm.). Given the surrounding environment at the time of site formation, it is very likely that the Tangzigou people utilized bamboo as tools but this is still not conclusive. Microwear studies using scanning electron microscope (SEM) may provide convincing evidence of bamboo tool use in butchering. West and Louys (2007) showed

morphological differences in cut marks made with stone tools and bamboo knives examined under SEM. Casts for the possible cut marks from Tangzigou have been made and are currently being studied with SEM by one of us (JJ) for further comparison with the published data.

The low number of percussion marks is puzzling. Actualistic studies showed if hominids had first access to the carcass (rather than carnivores) to extract marrow, ~ 28% of the assemblage displayed percussion marks (Blumenschine, 1995; Capaldo, 1997, 1998; Marean et al., 2000). Multiple lines of evidence suggest that humans were extracting marrow at Tangzigou but left very few percussion marks on the bones. A similar situation was found in Yuchanyan where only 1% of the assemblage showed percussion marks (Prendergast et al., 2009). One possible explanation for the discrepancy between the actualistic studies and the Tangzigou assemblage is the amount of soft tissue left on the bones when hit by hammerstones. Bones used in the experiments were completely disarticulated and defleshed before they were broken (Blumenschine and Marean, 1993; Capaldo, 1997) which might have left the bone surface well exposed. If Tangzigou people were using bamboo knives and leaving very few cut marks while defleshing, it is quite possible that some amount of soft tissue was still attached to the bones and covered the bone surface. It is not known how much effect soft tissue will have on changing the number of percussion marked bones and further research is warranted to explain the low percentage of percussion marks on Tangzigou bones.

2-5. Conclusions

The evidence of resource intensification during the Late Pleistocene and Early Holocene boundary has been documented from various sites around the world including China. Extensive use of carcasses and expanding dietary breadth are a few of the classic signs of intensification. It is not unusual to find archaeological sites in China with domesticated plants and animals, sedentary village, sophisticated burials and various types of pottery around 10,000 BP (Lu et al., 2009). Research on Yuchanyan archaeofauna from south China showed signs of intensification as early as ~15,000 BP (Prendergast et al., 2009). Given the younger age of Tangzigou, one might expect to find a similar pattern. Our study, however, has not found such evidence.

Even though a wide variety of animal species was included, a large portion of the Tangzigou diet depended on relatively few species mainly different sizes of cervids and a large bovid. Within those species, prime-aged animals were the primary target of the Tangzigou hunters. Carnivores could destroy the less dense juvenile bones making the assemblage appear prime-aged dominated. However, multiple lines of evidence suggest that carnivores were not the major bone accumulator at Tangzigou. The skeletal part profile, bone breakage pattern, and bone surface modification analyses of the Tangzigou assemblage show negligible evidence of carnivore activities.

After being hunted by humans, animals were brought into the site. Differential transportation strategy was observed among different body size groups perhaps based on their ease of transportation. Tangzigou people were butchering the carcasses leaving very few cut marks

perhaps due to using other raw materials than stones such as bamboo knives or because they did not need to fully scrape the flesh off the carcasses. Most of the marrow-containing bones were broken but no correlation was found between the marrow yield and the intensity of breakage. Grease was not processed leaving the epiphyses unbroken. The absence of pottery and no evidence of fire support the fact that grease was not part of the Tangzigou diet. Overall the Tangzigou assemblage reflects a hunting subsistence pattern based in a rich local environment that did not require intensification.

It has been well acknowledged that the true Neolithic culture started several thousand years later in southern China, especially in Yunnan, when compared to other parts of China (Huang and Zhang, 2002). The earliest sites in Yunnan with settlement, burial, and pottery date only to 4400-4100 BP (Higham, 2002). There are much older neighboring sites from southern China and Southeast Asia with classic Neolithic culture. The reason we do not see this in Yunnan is probably due to its unique geographical and ecological setting. Yunnan is largely isolated from the adjacent areas by its several high-peaked north-south running mountain ranges. This setting should have hindered the dispersal of the animals including humans and cultures. Despite the huge range it covers, Yunnan is one of the least populated provinces in China today. The situation would not have been much different in the Early Holocene. The people already residing in Yunnan must have enjoyed the rich natural resources including hundreds of endemic plants and animals (Kunming Institute of Zoology, 1999). Plentiful natural resources combined with low population density would have created pockets of favorable habitation areas for the people around Tangzigou. Although resource intensification is a widespread trend found during the Pleistocene-Holocene transition, there

is no reason to assume that people in Yunnan followed the same track during Tangzigou times.

Given the different environment and habitation history of Yunnan from the southern China and the more distant southern Levant, it is not unexpected to find an assemblage with different archaeological signatures. The interpretation here is still a hypothesis based on just one site that requires further testing. The lack of zooarchaeological and taphonomic studies from China and Southeast Asia in this important time period frustrates comparisons. Hopefully we will see more of such analyses in the near future that will allow diachronic and inter-site comparisons. Only then we will understand the true meaning of the subsistence pattern from Tangzigou.

Chapter 3

Split phalanges from archaeological sites: evidence of nutritional stress?

Authors: Jin, J., Mills, E., and Dutcher, M.

3-1. Introduction

The interpretation of zooarchaeological assemblages requires caution because the exact activities involved in prehistoric hunting and butchering are unknown. Ethnographic studies of the contemporary hunter-gatherers and actualistic studies with controlled experiments have provided valuable insights in filling this gap (e.g., Yellen, 1977a, b; Binford, 1978, 1981; Brain, 1981; Shipman, 1983, 1986; Shipman and Rose, 1983a,b; Bunn et al., 1988; O'Connell et al., 1988, 1990, 1991; Blumenschine, 1988, 1995; Marean et al., 1992; Bartram, 1993; Lupo, 1994; Monahan, 1998; Abe, 2005). These studies have documented the relationship between human foraging behavior and the pattern of faunal assemblages produced as a result. The mode of carcass acquisition (i.e., hunting vs. scavenging), carcass treatment and transportation decision are the topics that have generated vigorous and fruitful discussions and debates in the past thirty years.

It became evident that tremendous variation exists in the foraging behavior. Differential carcass transportation is a good example. The Nunamiut field processed caribou carcasses and selectively transported the body parts with higher edible meat yields (Binford, 1978), while the Evenki of Siberia transported the whole reindeer carcass regardless of its nutritional utility (Abe, 2005). The Hadza fillet meat prior to transport leaving the bones at the kill/processing site (O'Connell et al., 1988), while the !Kung and Okiek usually fillet at

the residential sites (Yellen, 1977a,b; Marshall, 1991, 1994). This variation makes it difficult to interpret the skeletal element representation and bone surface modification data from archaeological sites.

The optimal foraging model of behavioral ecology has become a powerful analytical tool to explain this variation by examining the underlying factors in foraging decision making. The assumption of the optimal foraging model is that "the goal of foraging is to maximize the overall energy return-rate" (Kelly, 1995: 83). Although different foraging groups share the same goal, variation in behavior exists due to the difference in such factors as group size, environment, the needs for storage and culinary tradition.

A consistent relationship has been found between the mean foraging return rate and the degree of carcass-processing in contemporary foraging groups in spite of the variation in hunting and butchering behavior (Burger et al., 2005). That is, people will make the most cost-efficient choice based on the amount of nutrients and processing time associated with different animal body parts (Jones and Metcalfe, 1988; Bettinger, 1991; Kelly, 1995; Lupo, 1998; Madrigal and Holt, 2002; Bird and O'Connell, 2006). The forager is expected to stop processing the carcass at the point when the rate of gain decelerates significantly despite of the prolonged handling time (Charnov, 1976; Kelly, 1995; Burger et al., 2005).

The optimal foraging model predicts that a forager will process the body parts with low return rate, such as mandible, scapula, and phalanges, when the higher return food resource is scarce. Thus, intensive processing of the low return rate bones has been commonly

interpreted as an evidence of nutritional stress. Cervid and bovid phalanges from Tangzigou, an 8800 year old archaeological site from southwestern China, were broken extensively suggesting that the Tangzigou people might have been under resource stress during the time of site formation (Jin, 2010; see below). However, the analysis of other skeletal elements with higher return rates from Tangzigou did not show evidence of intense processing.

In this paper, we articulate and test the optimal foraging hypothesis using the seemingly contradictory dataset from Tangzigou, arguing that the intensively processed phalanges in and of themselves cannot be an evidence of resource stress. First, we present the results of experimental studies conducted on 142 modern cow and deer first phalanges (PH1) to document the processing of phalanges, such as the required force and processing time to break them open, possible methods of breaking phalanges, and the resultant breakage and surface modification patterns. This comparative dataset and ethnographic data are then compared with the broken phalanges from zooarchaeological assemblages such as Tangzigou.

3-2. Background and hypothesis

Phalanges are usually perceived as bones not worth processing because of two reasons. First, phalanges contain no consumable meat and have little marrow in the first and second phalanges and none in the third one. In contrast with observations of phalanges as food sources, the femur, one of the highest-utility body parts, yields approximately fifteen times more calories than the first phalanx in caribou (Jones and Metcalfe, 1988). Metapodial, one of the low-utility body parts, yield five times more calories than the first phalanx in caribou (Jones and Metcalfe, 1988). If only the amount of marrow is considered, femur contains

thirty times more marrow than the phalanges in bison and fifteen times more than in white-tailed deer phalanges (Emerson, 1990; Madrigal and Holt, 2002). Second, phalanges are difficult to access due to the tough surrounding ligaments and tendons. Even if the soft tissue is removed, half of the second phalanx and the whole third phalanx are still embedded in the hoof making it hard to access (Figure 3.1).

Because of these two reasons, the Nunamiut did not think of phalanges as marrow-bearing bone and the processing of phalanges was not observed during Binford's stay with the Nunamiut (Binford, 1978). The older informants, however, pointed out that they broke the phalanges for marrow when the food was scarce (Binford, 1978). This led Binford (1978) to argue that the intensity of phalanx processing can be used as "a measure of the subsistence security enjoyed by a group at the time of observation" (p. 32). Ever since Binford's (1978) observation, phalanges have been considered to be a food resource that was butchered during hard times when people were under nutritional stress (Jones and Metcalfe, 1988). Intensively broken phalanges from archaeological sites have therefore been interpreted as an evidence of resource scarcity (Munro and Bar-Oz, 2005; Bar-Oz and Munro, 2007; Hall, 2007; Hill, 2008).

The intensity of carcass processing can be detected from a zooarchaeological assemblage by analyzing the degree of bone fragmentation, that can be measured by the % completeness (complete bone MNE/total MNE) and fragmentation ratios (NISP: MNE) (Outram, 2001; Burger et al., 2005; Munro and Bar-Oz, 2005; Bar-Oz and Munro, 2007). Intensively processed carcasses will have a low % completeness ratio and a high fragmentation ratio.

Figure 3.1. Artiodactyl foot anatomy
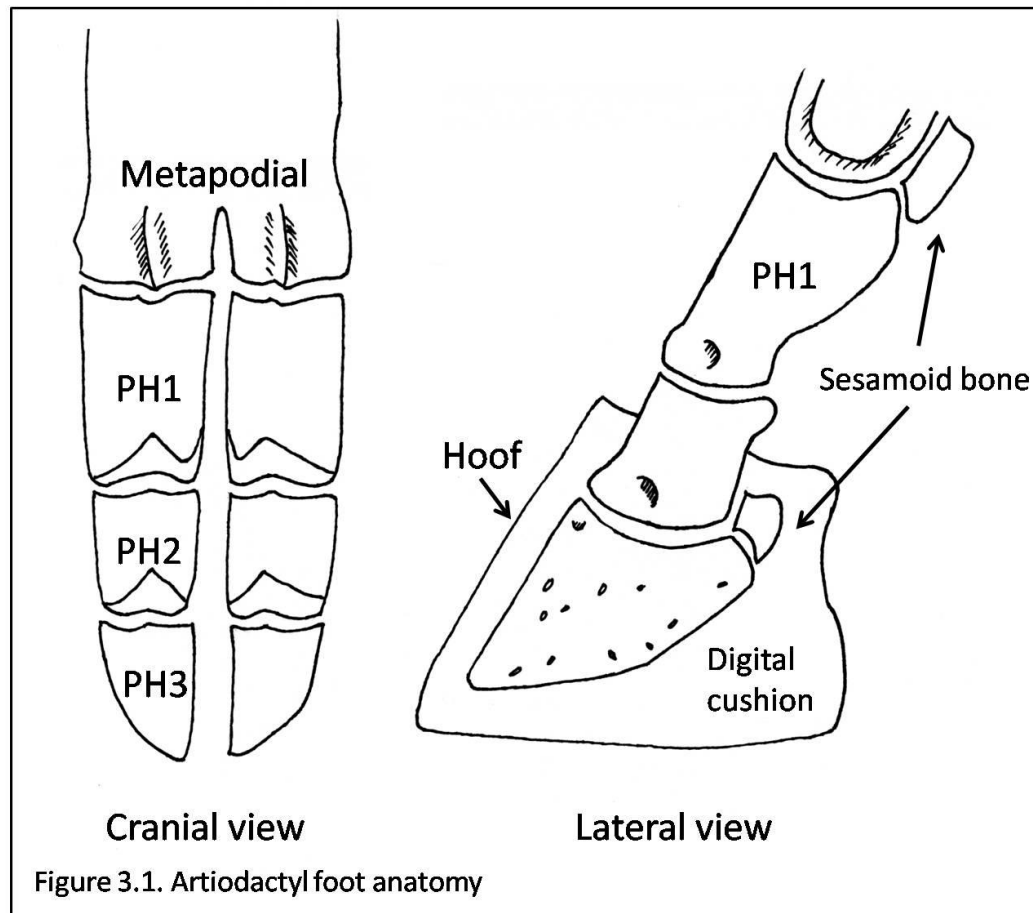
These two indices will likely to show significant correlation with the marrow yield in each skeletal part (Munro and Bar-Oz, 2005). The underlying assumption is that people under resource stress will process the higher-utility bones more intensely before they start processing the lower-utility bones. The gazelle assemblages from five Epipaleolithic sites in the Levant is a case in point. Munro and Bar-Oz (2005) showed significant positive correlations between the fragmentation ratio of the skeletal elements and their marrow yields. The marrow-bearing gazelle PH1 and PH2 showed low % completeness compared to the non marrow-bearing PH3 and astragalus (Munro and Bar-Oz, 2005). This evidence was used to support the argument of resource scarcity and extensive utilization of the animal carcasses

(Munro and Bar-Oz, 2005). Prendergast and colleagues (2009) used the same method to show that the extensive breakage of the deer phalanges from a Late Pleistocene cave site in southern China was evidence of resource intensification.

3-3. Faunal assemblage from Tangzigou

Tangzigou (N 25º 1´ 31″, E 99º 0´ 28″; 1360 meters above sea level) is an open-air archaeological site located in Yunnan Province of southwest China. It was Accelerator Mass Spectrometry radiocarbon dated to 9000-8800 cal BP, a crucial time period in human prehistory when the transition from a mobile, foraging-based to a sedentary, agriculturally-based economy had started in various parts of the world. Since its first excavation in 1987, Tangzigou has been excavated several times, most recently in 2003 and 2006. All of the excavated sediments were meticulously dry- and wet-sieved through 3 mm mesh screens. Numerous stone and bone tools, vertebrate and invertebrate fossils, and plant macrofossils have been discovered. No pottery was found. One of us (JJ) studied the mammal fauna that consisted of 5358 identifiable specimens and 3360 unidentifiable fragments. Cervids and bovids are the most abundant taxa. Small cervids, the size of a muntjac, dominate the cervid assemblage (53 % of the total NISP). Sambar-sized large cervids (22%) and water-buffalo-sized large bovids (19 %) are the next most abundant groups.

Zooarchaeological and taphonomic analysis of the Tangzigou faunal assemblage found no evidence of resource scarcity at the time of site formation (Jin, 2010). Although the long bones were processed for marrow, the marrow yield did not correlate significantly with the

intensity of breakage, refuting the interpretation that the bones were intensively processed

(small cervids, r = 0.154, p = 0.599; large cervids, r = -0.325, p = 0.257; large bovids, r =

-0.420, p = 0.135). Logically, people under high subsistence stress should process every bit

of the within-bone nutrient, thus producing a highly fragmented bone assemblage (Outram,

2001). However, the overall fragmentation ratio (NISP: MNE) of the Tangzigou assemblage

is significantly low compared to the above mentioned sites in the Levant and south China

(Table 3.1).

Table 3.1. Fragmentation ratio of the long bones from multiple sites and the results of
independent sample t-test between Tangzigou and other sites

	Tangzigou	Yuchanyan	NHV KEB	HEF G-KEB
Humerus	1.56	6.57	10.8	8
Radius	1.83	6.67	7.3	7.3
Femur	2.1	4.25	11.3	7.5
Tibia	1.76	6	6.9	8.5

	Tangzigou VS.		
	Yuchanyan	NHV KEB	HEF G-KEB
t	-7.1	-6.3	-20.7
df	3.2	3.1	4
p	< 0.005	< 0.05	< 0.001

*Yuchanyan data from Prendergast et al., 2009
* NHV KEB, HEF G-KEB data from Bar-Oz and Munro, 2007

The conclusion drawn from these analyses is that Tangzigou people enjoyed abundant local

resources but did not intensively process carcasses (Jin, 2010). The optimal foraging model

predicts that, in an assemblage such as this one – which was not intensively processed – the

phalanges will be largely untouched due to the small caloric return rate. Contrary to this

expectation, ~70 % of the first and second phalanges (NISP = 538) at Tangzigou were split

open. Thus, this consistent and repetitive breakage pattern of the phalanges is both surprising, given the lack of resource stress, and indicative of systematic butchering behavior by humans.

Interestingly the phalanges showed different breakage pattern based on the animal's body size. The majority of the large bovid (water-buffalo-sized) first and second phalanges (NISP = 171; 69 %) were longitudinally split while the small and large cervid ones were transversely split (Figure 3.2). Longitudinally split large bovid phalanges generally retained their whole length (i.e., proximal and distal ends and the entire shaft is preserved) and were broken along the midline longitudinal axis of the bone. The fracture outlines were very clear with a smooth fracture edge.
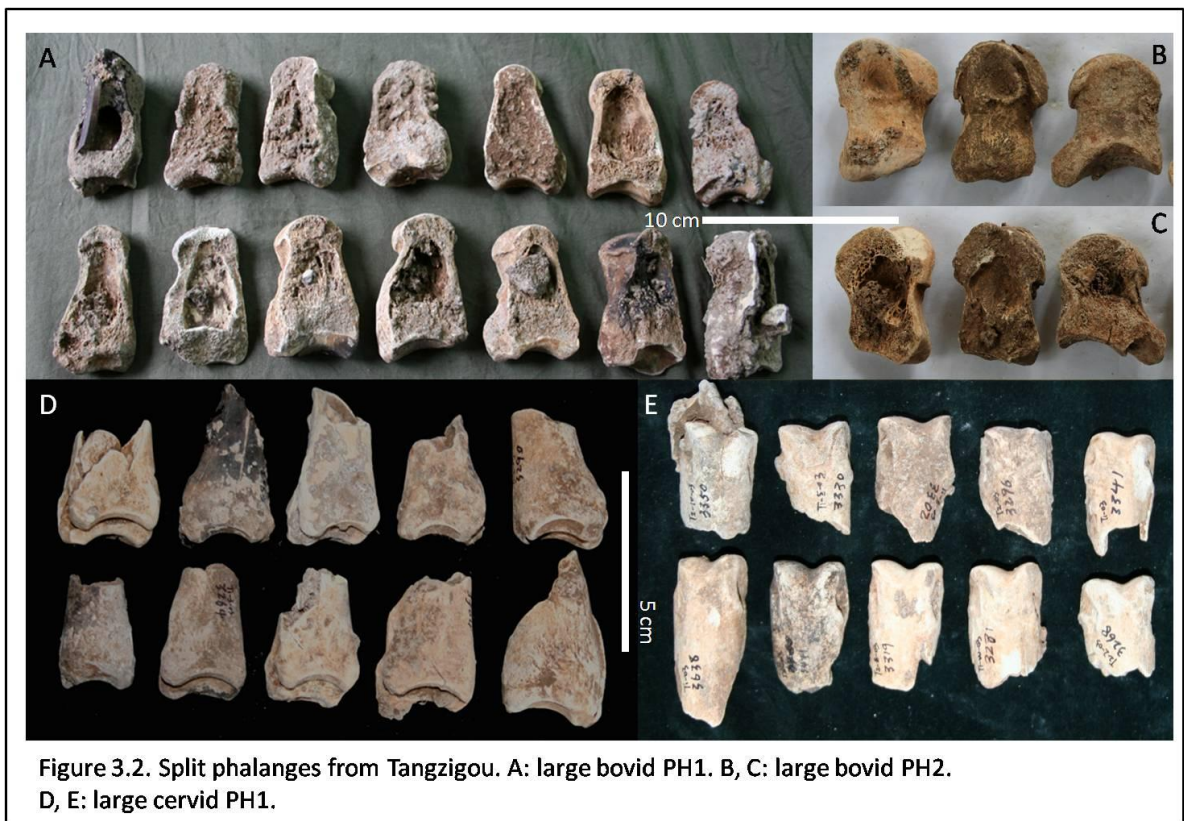
Figure 3.2. Split phalanges from Tangzigou. A: large bovid PH1. B, C: large bovid PH2. D, E: large cervid PH1.

The question then is why the Tangzigou phalanges were extensively processed during a time when people were not under nutritional stress. We hypothesize that intensive processing of the Tangzigou phalanges in and of itself is not an evidence of resource stress.

Before we draw any inference on the human behavioral aspect of the phalangeal processing at Tangzigou or elsewhere, the possible effect of carnivore ravaging must be examined. Phalanges contain marrow and grease, albeit in small quantities, that could potentially attract carnivores. Carnivores tend to swallow the whole phalanges of a sheep/goat size animal during the consumption of the feet (Haynes, 1980, 1982; Marean et al., 1992; Madrigal and Capaldo, 1999; Pokines and Kerbis Peterhans, 2007). After going through the digestive system, phalanges and hooves are normally regurgitated with signs of acid etching (Sutcliffe, 1970; Lyman, 1994: his figure 6.24). Small holes and tooth marks from carnivore gnawing were frequently found on the phalanges from modern and Upper Pleistocene carnivore den faunas in Italy (Stiner, 1994: 146; also see Lyman, 1994: his figure 6.20). The phalanges were rarely opened by carnivores (Stiner, 1994; R. Graham, pers. comm.).

Carnivore ravaging can be rejected as the cause of the splitting of phalanges at Tangzigou. No signs of gnawing or digestion were found on the Tangzigou deer phalanges, and the phalanges of a water-buffalo-sized animal would have been difficult for carnivores to swallow whole (Jin, 2010). Therefore, we conclude that the observed phalangeal breakage at Tangzigou was the result of human behavior. Our conclusion is similar to that of Stiner (1994 and her figure 5.30) who found most of the deer and aurochs phalanges from the Paleolithic cave sites in Italy were split open with consistently clean break edges – closely

resembling those from Tangzigou – which she interpreted as evidence of human processing for marrow.

3-4. Materials and Method

A total of 28 white-tailed deer feet (56 PH1) from seven individuals were obtained between October and December 2008 through the Penn State Deer Research Center and from a local hunter. The deer feet from the Penn State Deer Research Center were from six euthanized does from 2.5 years to 9.5 years old (Table 3.1). One male deer of unknown age was hunted by the local hunter. A total of 43 cow feet from 12 individuals were obtained between October 2008 and December 2009. Twenty nine feet (58 PH1) were from the cows younger than 2 years old slaughtered at Penn State Meats Lab. Fourteen feet (28 PH1) were from the cull dairy cows older than 4 years slaughtered at Cargill Taylor Beef Plant in Pennsylvania.

Table 3.2. Cow and deer samples used in the experiments

Cow	Age	Total sample size	Deer	Individual No.	Age	Sex
	Young (< 2 years)	29 feet		8029	2.5	Female
	Old (> 4 years)	14 feet		8020	2.5	Female
				5011	5.5	Female
				4042	6.5	Female
				4009	6.5	Female
				142	9.5	Female
				No number	Unknown	Male

The feet were cut off immediately after the individual died and kept in the freezer until the experiment began. Prior to the experiment, the feet were removed from the freezer for at least 24 hours to fully thaw. In the preliminary stage, one cow foot was skinned using

hammerstones and blunt stone flakes to determine whether a robust cow foot could be
butchered without using sharp tools, because only such crude and blunt stone tools were
available at Tangzigou. Once we successfully skinned and accessed the phalanges with stone
tools, we used metal knives in the rest of the experiments.

The feet were prepared in two different ways for the experiment (Figure 3.3). One group was
comprised of complete articulated feet below the metapodials (i.e., sets of 1-3 phalanges
attached to each other). The feet in the other group were disarticulated into smaller units (i.e.,
1-3 phalanges separated from each other). In our experiments, we focused only on the first
phalanges. The bones were laid on a large stone block with the cranial side up and hit with
large rocks and pebbles until they broke (Figure 3.4). Five healthy male archaeologists
carried out this procedure.

Figure 3.3. Two different ways of phalanges preparation for the experiments. PH1 is articulated to other foot bones in group 1. In group 2, PH1 is disarticulated.
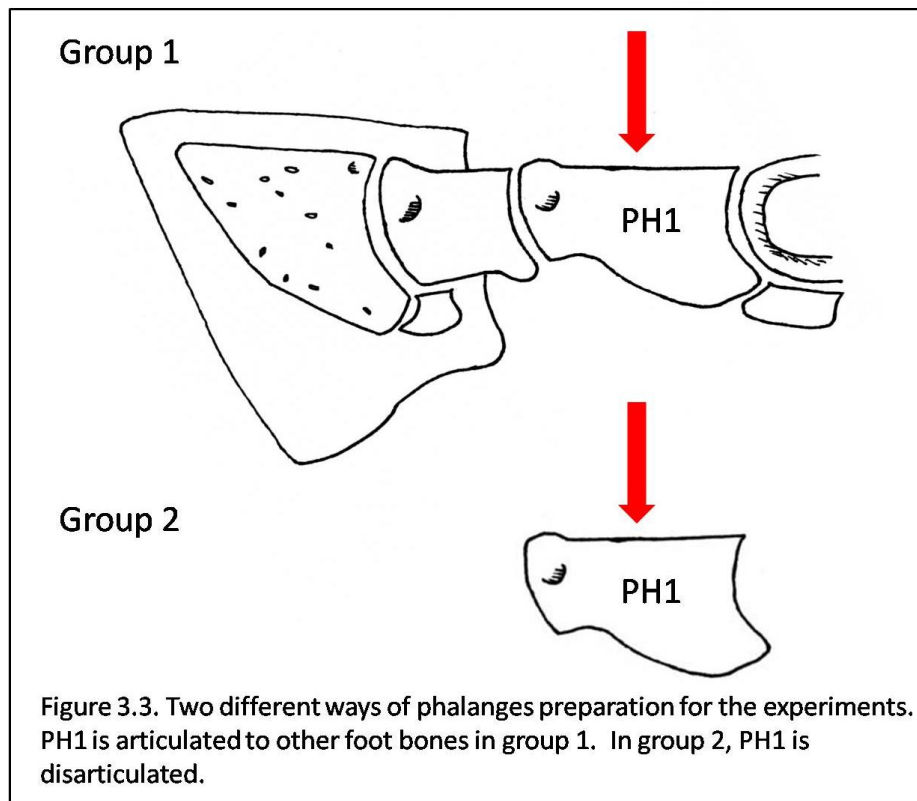
Figure 3.4. Cow foot experiments. (Top row) Before and after skinning, (bottom row) hammerstone and anvil used in experiments.

Broken bones were cleaned for further analysis using two different methods: dermestids and boiling. Six deer and ten cow PH1s were processed in a dermestid beetle colony. Each bone took several days to be fully cleaned. The other specimens (50 deer and 76 cow PH1s) were boiled to remove the soft tissue and marrow, after weighing the marrow to the nearest .01 g using an electric scale before boiling. Cleaned and dried bones were refitted and then data were collected on bone breakage pattern and bone surface modification. Following Villa and Mahieu (1990), the fracture angle of each piece was recorded as longitudinal, transverse, or oblique to the proximal-distal direction of the bone midline axis and the fracture edge was

recorded as smooth or irregular. Percussion marks were identified using a 16x hand lens under strong incandescent light (Blumenschine and Selvaggio, 1988).

3-5. Results: Processing time, Breakage Patterns, and Refitting

Cow phalanges

It took 30 minutes to skin the cow foot and to separate the PH1 using hammerstones and flakes. This processing time may have been extended because the butchers were not practiced in this endeavor and used relatively blunt tools. With steel knives, the skinning time shortened for a novice butcher (JJ) was still 25 minutes, while a highly skilled and experienced butcher (EM) accomplished the task in less than ten minutes. Disarticulating the PH1 from the other bones did not require intensive extra work because the bone was not embedded in the hoof. Once the foot was skinned, tendons and ligaments at the metapodial/PH1 joint and the PH1/PH2 joint could be separated within a minute using metal knives. The skinning time was significantly shortened as we processed more feet and became familiar with the procedure.

It took at least 8-10 strong blows to break open the PH1 when it was attached to the metapodial and PH2. In contrast, the disarticulated PH1 was broken easily with only 1-2 blows. A total of 82 of the 86 PH1s were able to be refitted but six specimens from the articulated PH1 group were too fragmentary to be refitted.

There was a striking difference in bone breakage pattern between the articulated and the disarticulated phalanges. The articulated PH1s (n=34) were broken in random directions
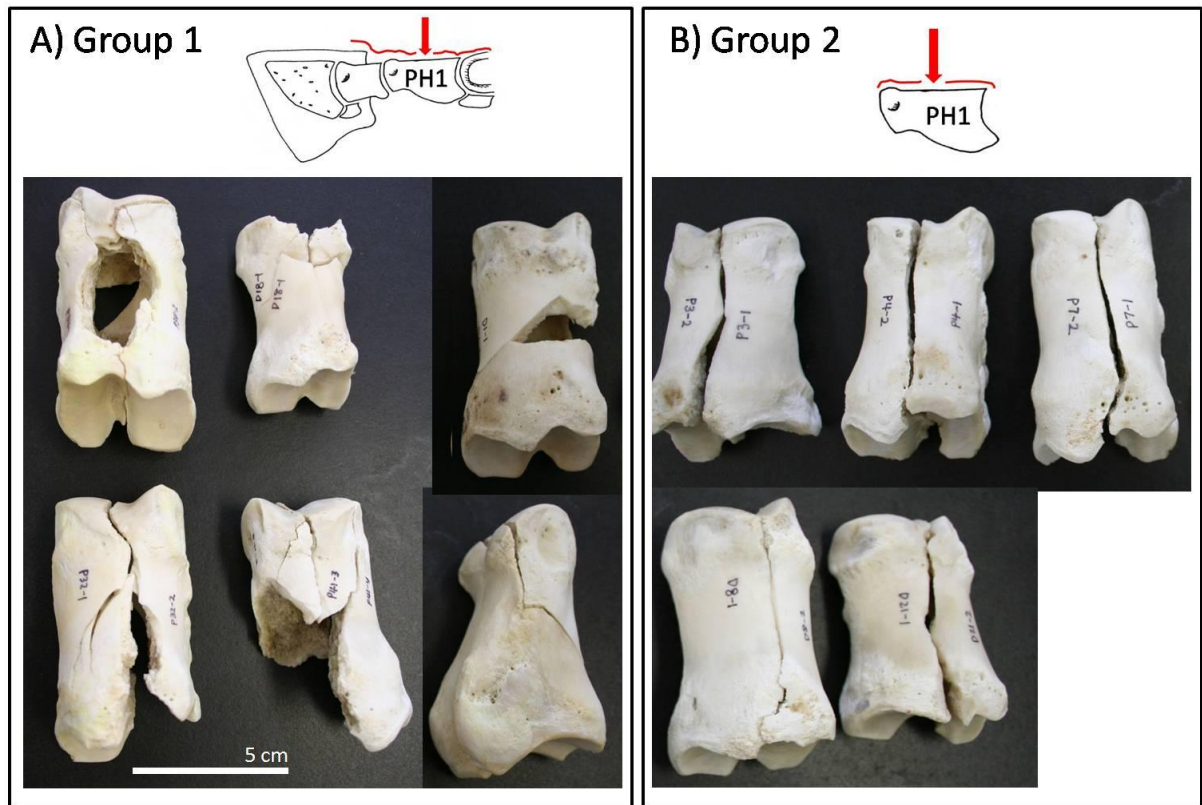
Figure 3.5. Different breakage pattern between the articulated (group 1) and disarticulated (group 2) phalanges.

with smooth and irregular fracture edges (Figure 3.5a and 3.6). A large round hole was the most common (23 %) breakage pattern observed within the articulated PH1 specimens followed by a partial transverse breakage and oblique split. Although a longitudinal split was also observed in the three articulated specimens, the split did not follow the mid-line axis of the bone and the fracture edge was irregular. Layers of bone flakes were commonly observed around the percussion point (Figure 3.7). All of the phalanges that were disarticulated prior to the hammerstone blow (n=48) were split longitudinally along the midline axis of the bone with smooth fracture edges (Figure 3.5b and 3.8). There was no difference in the breakage pattern based on the individual's age.

Figure 3.6. Breakage patterns of the phalanges in group 1

Figure 3.7. Close-up shots of the three specimens (A, B, C) from figure 3.6. Note the layers of bone flakes around the percussion point.
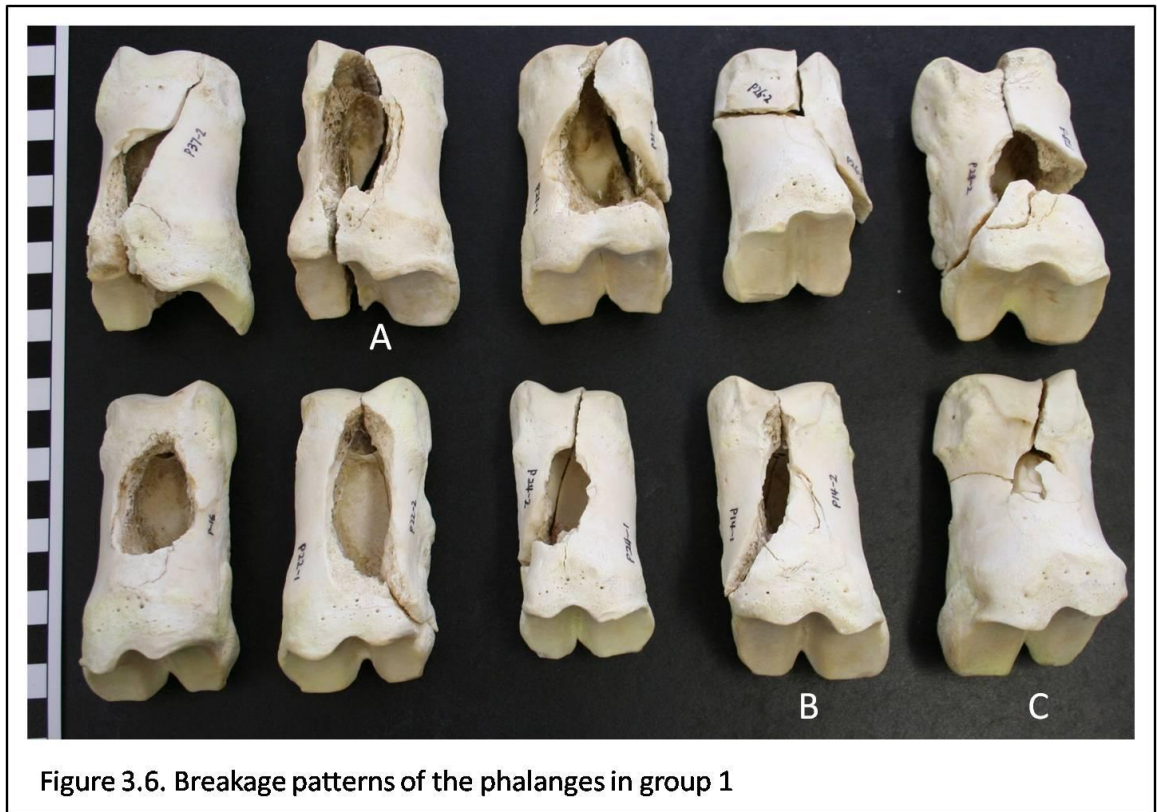
Each broken piece (100 from disarticulated PH1s and 64 from articulated PH1s) was examined for percussion marks. There was a significant difference in the frequencies of percussion marks between the two groups ($\chi^2 = 19.33$, df = 1, n=164, p < 0.001). In the disarticulated PH1s, 9 % (n=9) of the fragments showed percussion marks. Articulated PH1s had a much higher percentage of percussion marks (39 %; n=25).

Figure 3.8. Breakage patterns of the phalanges in group 2
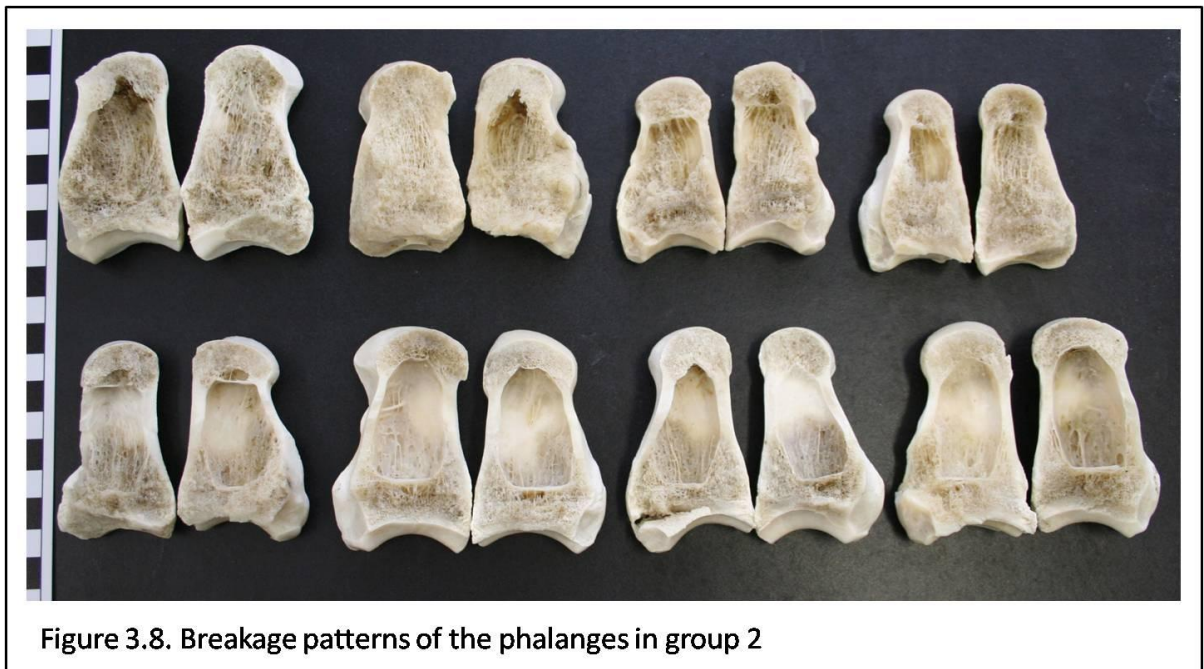
Forty-two percent (n=20) of the disarticulated PH1s showed more heavy breakage on the caudal side, although the impact blow was delivered on the cranial side (Figure 3.9). The cranial side showed a relatively straight line of fracture while part of the bone was chipped away on the caudal side especially towards the proximal end. This was not an expected pattern to find when we were planning the experiment. After carefully examining the broken phalanges, we hypothesized that this particular breakage pattern might be from the difference in cortical bone thickness. Cortical bone is thicker on the cranial side of the PH1, thus is

more able to absorb energy from direct percussion while the thinner caudal side is more

fragile and more prone to bone breakage. In order to test this hypothesis, we measured the

cranial and caudal cortical thickness of 59 cow PH1 specimens that were split longitudinally

(Figure 3.10). Independent samples t-test showed a significant difference in cortical between

the cranial and caudal sides (t = 13.419, df = 94, p < 0.005).
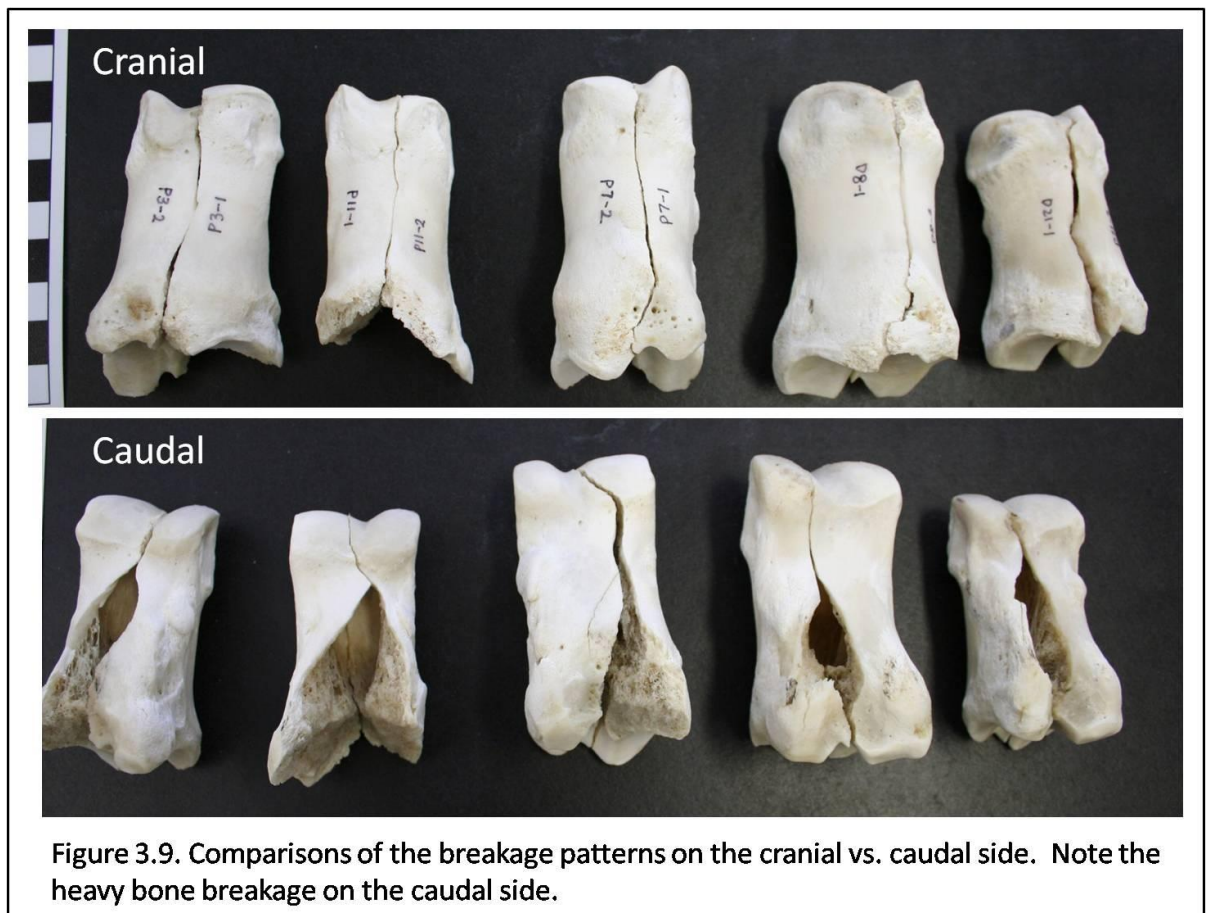
Figure 3.9. Comparisons of the breakage patterns on the cranial vs. caudal side. Note the heavy bone breakage on the caudal side.

Figure 3.10. Measuring cortical thickness of the PH1 on cranial (CR) and caudal (CA) side.
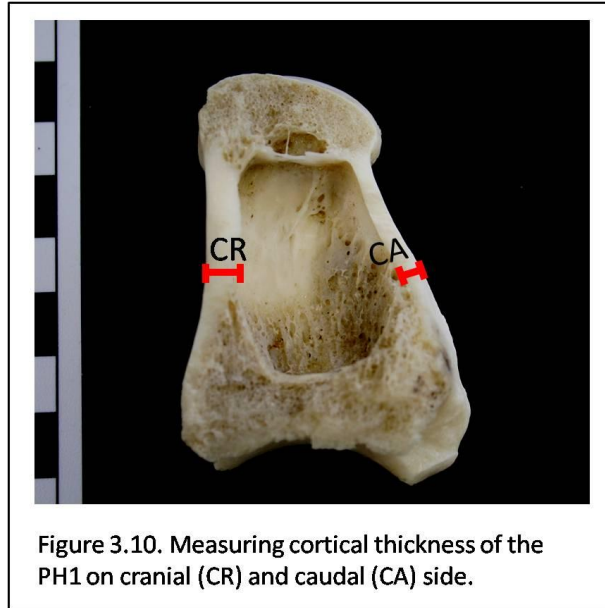
About a teaspoonful of marrow was easy to access once the PH1 had been longitudinally split (Figure 3.11). The average wet weight of marrow for 36 PH1 was 5.1 g (range: 2.7 g to 8 g). Marrow was more difficult to retrieve from the remaining fifty specimens because marrow was scattered or lost during the experiment, especially in those involving the articulated PH1.

Figure 3.11. Longitudinally split PH1s. Note the teaspoonful of marrow in medullary cavity.
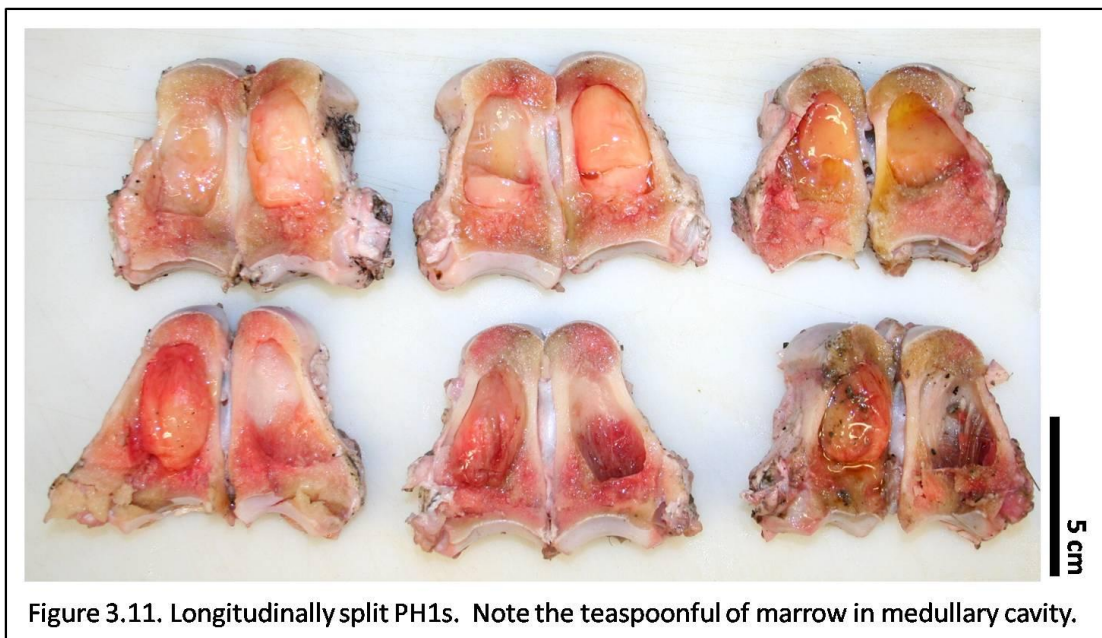
Deer phalanges

Skinning and separating the PH1 was easier in cervid specimens (n=56) than in the bovid specimens. However, the disarticulated PH1 specimens were difficult to handle due to their small size. Seventy-five percent (n=42) of the deer PH1 were recovered after processing and, of these, 15 PH1s were refitted completely while 27 PH1s were partially refitted; the small size of the fragments made refitting impossible in the other specimens.

Unlike the bovid PH1s, cervid PH1s showed no difference in their fracture patterns that related to whether they were articulated or disarticulated at the beginning of processing. The breakage pattern was determined by the force applied to the bone during the experiment, not by the way PH1 was prepared. Fourteen PH1s were completely smashed during the experiments because we hit the bone too hard. Among the retrieved phalanges, transverse fracture was the most commonly observed (83 %) breakage pattern followed by spiral fracture (17 %) (Figure 3.12). No longitudinal splits were found. Percussion marks were found on the eight refitted phalanges (19 %). The average marrow weight for five PH1 was 0.77 g (range: 0.67 g to 0.92 g), but an accurate weight for the marrow in the other specimens could not be determined because of extensive shattering.

Figure 3.12. Broken deer phalanges from the experiments. No longitudinal split was found.

3-6. Discussion

3-6-1. Reconstruction of the possible method for processing phalanges

The PH1 can be broken relatively easy with one to two blows on the cranial surface when it is disarticulated from the metapodial and second phalanx prior to breakage. This method produced a consistent breakage pattern (i.e., longitudinal split for bovids and a transverse/spiral split for cervids) with smooth fracture edges that closely resembled the breakage patterns of the Tangzigou phalanges. Although it took extra time to disarticulate the PH1 from the other bones, this cost was offset by the subsequent ease and speed of breaking open the PH1. The advantage of breaking the PH1 after disarticulating it from other

bones is the predictable and consistent breakage pattern that this method produces. This procedure would have allowed prehistoric people to securely access a spoonful of marrow without having to be concerned about bone chips and marrow scattering. Therefore, this procedure seems to be the most likely method that Tangzigou people would have used to break the phalanges. Phalanges from other sites with a similar breakage pattern are also likely to have been processed with this method.

The difference in the breakage pattern between bovid and cervid phalanges at Tangzigou is most likely to be the result of the difference in bone size not the breaking method. A similar difference in the breakage patterns was found in various other archaeological sites. Eighty nine percent (n=39) of the horse PH1s from the Magdalenian IV site were longitudinally split along the midline axis of the bone (Bouvier, 1979: his figure 1). Bouvier (1979) conducted a small scale experiment with modern horse phalanges to examine whether that was the natural breakage pattern for such bones. He successfully reproduced longitudinally split phalanges by hitting the disarticulated PH1 about five times with a hammerstone (Bouvier, 1979). A similar pattern was found in Caldas Cave, a Late Upper Paleolithic site from Spain by Mateos Cahorro (1999, 2005). Again, the phalanges were extensively broken with the same pattern we observed in our experimental studies; the *Bos/Bison* and *Equus* phalanges were more frequently broken longitudinally while the *Cervus* and *Capra*/*Rupicapra* phalanges were broken transversely and spirally (Mateos Cahorro, 1999, 2005 (see her figure 6.150); A. Mateos, pers. comm.). Bison phalanges from the North American Paleoindian sites were broken in an almost identical way to the Tangzigou large bovid phalanges (M. Hill, pers.

comm.), while the deer phalanges showed spiral breakage patterns (Hall, 2007: his figure 5.2).

Interestingly the Barbary sheep phalanges from the Tamar Hat Rockshelter Zone I in Algeria showed a distinctive breakage pattern not found in our experiments. Tamar Hat Rockshelter is dated to 14,000-20,000 cal BP and has been interpreted as a site where people selectively hunted the prime-age Barbary sheep (Merzoug and Sari, 2008). Among the 51 PH1s found, 28 were split longitudinally and 23 were broken spirally (Merzoug and Sari, 2008). The authors argued that the spiral fractures were produced by direct percussion while the longitudinal fractures were the results of indirect percussion (Merzoug and Sari, 2008: their figure 6).

Our data support this interpretation. Our samples were all hit with direct percussion and none of the cervid PH1s –which are of roughly comparable size to sheep phalanges–broke longitudinally. Therefore, we suggest that the longitudinal fracture of the Barbary sheep PH1 is likely to be the result of a different breaking method. As suggested by Merzoug and Sari (2008), a sharp tool was probably wedged in the depression between the proximal articular surfaces and then was hit with a larger object. This method would have been more time consuming than direct percussion because the small size of a Barbary sheep PH1 would have made handling difficult. The Tamar Hat people could have produced the longitudinal split of small PH1 to conserve the overall length of the bone for further use such as modifying it into a fish hook (Guilday et al., 1962: their figure 9).

3-6-2. Bone breakage patterns and bone surface modification

Bovid PH1s from our experimental studies produced an intriguing bone loss pattern. Bones were frequently chipped on the opposite side of the percussion point. A similar pattern was found from the horse phalanges from the Magdalenian IV site (Bouvier, 1979). Bouvier (1979) observed that the PH1 were mostly damaged on the caudal side below the proximal articular surface (Bouvier, 1979). He assumed that the bone was hit on the caudal side with hammerstones (Bouvier, 1979). Contrary to Bouvier's (1979) idea, the PH1s in our experiments were chipped, not on the side where they were hit but on the opposite side towards the proximal end.

PH1 damage on the proximal ends has also been reported from Mousterian sites in Europe. The reindeer phalanges from Combe Grenal Mousterian deposit had holes on their proximal ends that were interpreted as Neandertal whistles by some researchers (Chase, 2001). Chase (2001) refuted the whistle hypothesis by conducting microwear studies. He convincingly argued that most of the holes were located on the proximal end not because of human activities but because that was the thinnest part of the bone which would have been affected by chemical action and carnivore chewing (Chase, 2001).

Our measurements of cortical thickness in phalanges suggest that the damage on the proximal caudal side of the PH1 is probably because that is the thinnest and most fragile area of the bone. The results of our experiments suggest that cortical thickness might be one of the key factors to understanding the PH1 breakage pattern. Further biomechanical research will be useful to solve the mechanism behind the peculiar breakage of the phalanges.

Among the bovid PH1s, percussion marks were more common in the articulated PH1 group (39 %) than in the disarticulated PH1 group (9 %; $\chi^2 = 19.33$, df = 1, p < 0.001) even though the bones in both groups were hit directly on the cortical surface. This is probably due to the difference in the distribution of percussion force and the number of blows. In the disarticulated PH1 group, the force was distributed along and around the midline axis, allowing the bone to break longitudinally. In the articulated PH1 group, however, the percussion force was absorbed not only by PH1 but also by the metapodial, PH2, PH3, and the soft tissues connecting them to each other. Although the articulated PH1 was also hit on the midline axis, the percussion force was not transmitted along and around the PH1 but was partially dissipated by the adjacent bones connected by soft tissue. As a result, breaking PH1 required more blows, i.e., more energy, due to the larger surface area and discontinuous material through which the percussion force was distributed. Continuous blows eventually broke the PH1 but breakage usually occurred around the percussion point, not as a longitudinal split along the midline axis. Consistent with this interpretation, a high frequency of percussion marks and bone flakes were found around the percussion point. Our data suggest that the overall breakage pattern of the phalanges provide a better evidence of human activities than percussion-generated surface modification (also see Darwent and Lyman, 2002).

3-6-3. Split phalanges from Tangzigou: evidence of nutritional stress?

Bone marrow has been an important nutritional resource for humans worldwide (Yellen, 1977a, b; Binford, 1978, 1981; Stiner, 1994; Outram, 2001; Munro and Bar-Oz, 2005).

Marrow can be extracted by breaking the bones. Thus, bone fragmentation data can shed light on the marrow extraction behavior. In the Tangzigou assemblage, marrow-bearing bones were more frequently broken than the non marrow-bearing bones suggesting that the Tangzigou people were processing bones for marrow (small cervids: $\chi^2 = 173.8$, df = 1, p < 0.005; large cervids: $\chi^2 = 88.1$, df = 1, p < 0.005; large bovids: $\chi^2 = 22.08$, df = 1, p < 0.005; Jin, 2010: her table 2.6). For instance, only 11 % and 32 % of the marrow-bearing PH1 (MNE=88.8) and PH2 (MNE=65.5) were complete in the small cervid group while 75 % were complete for the non marrow-bearing PH3 (MNE=170.5). It is evident from the breakage pattern and fragmentation data that the Tangzigou people broke phalanges for marrow despite the small yield and chose a breakage method that kept the marrow intact.

Ethnographic studies show different patterns in the use of animal phalanges. The !Kung used an axe to split open the first and second phalanges to remove the edible marrow (Yellen, 1977a,b). It has not been reported whether this is a behavior observed during periods of resource scarcity. The Hadza split the hooves with a knife to dig out the fatty tissue around the PH2 and PH3 but processing phalanges has not been observed (O'Connell et al., 1988). The Evenki of Siberia did not break the reindeer phalanges for marrow but used them occasionally to make a cold gelatin side dish by boiling and cooling them down (Abe, 2005). The Nunamiut processed phalanges for marrow but only during when food resource was not abundant (Binford, 1978).

Due to the long processing time and low caloric return, researchers have previously argued that marrow in the phalanges were extracted for consumption primarily when people were

under resource stress (e.g., Binford, 1978; Jones and Metcalfe, 1988; Munro and Bar-Oz, 2005). We suggest that this interpretation is particularly applicable to people in highly seasonal environments. The level of subsistence stress is cyclical; resources are scarce in late winter and spring (Speth and Spielmann, 1983; Speth, 1987). The animals people prey on experience the same seasonal nutritious stress (Harris, 1945). When the mammals are under resource stress, fat is one of the first elements that is depleted, not protein (Speth and Spielmann, 1983; Speth, 1987). Therefore, during "the hard time" the hunters are likely to get an insufficient amount of fat from the same numbers of hunted animals. Marrow in the phalanges is the last to be mobilized by nutritionally stressed deer (Harris, 1945; Speth and Spielmann, 1983; Speth, 1987; Jones and Metcalfe, 1988; Madrigal and Capaldo, 1999; Morin, 2007). Thus, marrow in the phalanges of a fat-depleted animal could have been the last reserve of fat available for the nutritionally stressed foragers.

Bison and pronghorn phalanges from an Early Paleoindian site in Agate Basin were more intensively fractured than the phalanges from other nearby sites and have been interpreted as an indication of periodic dietary stress (Hill, 2008). Although such a marginal food resource was utilized, the long bones with significantly more marrow were left untouched in the Agate Basin Folsom component (Hill, 2008). Hill (2008) argued that this reflected "an absence of supple bison carcass portions available for consumption" (p. 23) due to the severe cold weather during the winter. As the climate warmed up in the Holocene, a sharp increase has been reported in the frequency of marrow-containing bones with percussion marks (Hill, 2008). Deer and bison phalanges from a Late Holocene Oneota sites in central Iowa showed

a high occurrence of breakage along with the long bones, which lead Hall (2007) to conclude that people processed phalanges due to seasonal nutritional stress.

In the aforementioned situations, e.g., seasonal fat depletion and harsh environment, the optimal foraging model predicts that a forager will utilize a food resource with low caloric return rate, such as the marrow in the phalanges. This hypothesis, however, is not equally applicable to the analysis of the Tangzigou assemblage. We argue here that Tangzigou people and their prey animals were not likely to have undergone severe seasonal fat depletion because of the relatively aseasonal environment of the region (China Handbook Editorial Committee, 1983).

Therefore, we suggest that the broken phalanges by themselves do not necessarily reflect nutritional stress or intensive carcass processing in all environments. Contrary to the pattern observed among the Nunamiut, Tangzigou people processed the phalanges during the "good time" when the food resource was abundant. If the foragers had plentiful resources to hunt and gather with minimal effort, then they could afford the luxury of processing the bones with lower return rate for non-caloric related reasons. To Tangzigou people, phalangeal marrow may simply have been a special luxury food.

Because the optimal foraging model predicts that human behavioral choice is based on economic utility, deviation from this prediction suggests that the behavior in question is perhaps a product of "culture" and has little to do with maximizing net energy return (Kelly, 1995). For instance, the optimal foraging model predicted zebra to be in the diet of the

Valley Bisa in Zambia due to its high caloric return rate (Mithen, 1989). In reality, zebra were rarely hunted by the Valley Bisa (Mithen, 1989). This led the researchers to seek an alternative explanation other than maximizing caloric return rate (Kelly, 1995). The Bisa did not hunt zebras probably because of legal reasons or cultural taboo, e.g., "zebra flesh may carry the taint of social stigma" (Mithen, 1989: 77).

The "culture" hypothesis is difficult to prove or disprove unless other evidence on the subsistence pattern is available. Hall (2007) recognized this problem as well with his interpretation of the broken phalanges from the Late Holocene Howard Goodhue site. He concluded that the Howard Goodhue occupants were under nutritional stress, as was not only evidenced by the broken phalanges but also by the expanded diet breadth and intensively fragmented long bones (Hall, 2007). A similar conclusion is not supported by the Tangzigou data, since the analysis of the % completeness and fragmentation ratio of long bones do not show evidence of intense carcass-processing at the site, suggesting the broken phalanges may not be indicative of nutritional stress (Jin, 2010). Thus, an alternative explanation is sought for pattern of phalanx utilization at Tangzigou.

The phalanges from Tangzigou could have been processed for their marrow quality not quantity. Marrow in the phalanges is known for its better taste because of its high content of unsaturated fatty acids compared to other long bones (Morin, 2007: his table 3). Stefansson's (1944) ethnography from the Arctic showed that the Eskimos were well aware of the quality difference in the marrow from different bones. The marrow closer to the hoof was always more preferred to marrow farther away from the hoof because of its better taste and softer

texture (Stefansson, 1944). Although marrow from phalanges was not eaten often by the

Eskimos due to its long processing time, it was deemed the best tasting marrow compared to

the tallow-like marrow from humerus and femur (Stefansson, 1944).

Marrow in the phalanges could have been processed during when people consumed the fat

content in the hoof (i.e., digital cushion). The digital cushion is a fatty pad behind the PH3

made up of fat and a small amount of elastic fibers and cartilage (Lupo, 1998). Lupo (1998)

documented the average caloric return rate for the digital cushion and PH1 in impala,

hartebeest, wildebeest, and zebra. Her study showed that feet were among the highest ranked

parts for zebra and wildebeest, even higher than the limb bones (Lupo, 1998). This is due to

the large fatty pad in the large-bodied animals (Figure 3.13). The fatty pad in the ungulate

hoof is consumed by some contemporary hunter-gatherers (O'Connell et al., 1988) and also

served as delicacy in modern restaurants in Africa.
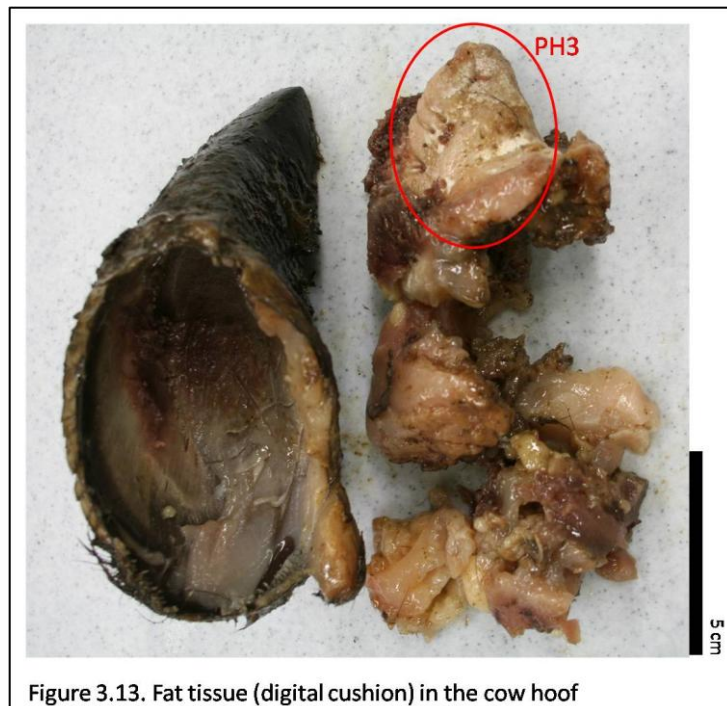
Figure 3.13. Fat tissue (digital cushion) in the cow hoof

Unfortunately consuming the digital fatty pad is not likely to leave any physical signatures for archaeologists to detect. We can only deduce that the fatty pad in the hoof would have been an important fat source for the prehistoric hunters. PH1 could have been disarticulated from the second phalanx in order to ease the access to the fatty pad. Our experiment showed that breaking a disarticulated PH1 was relatively easy with one to two blows, not as difficult as it has been perceived in the archaeological literature. If this were the case, broken phalanges cannot be used as a measure of subsistence stress without additional evidence.

The skeletal element representation of the Tangzigou assemblage showed that the large cervid and large bovid were represented by the low-utility body parts, suggesting that Tangzigou was a butchering site (Jin, 2010). Marrow in the Tangzigou phalanges could have been consumed while butchering the animal, a behavior observed in the contemporary hunter-gather groups. The Plains Indians snacked on bison organs and bone marrow while butchering (McHugh, 1972). For the Evenki hunters, marrow consumption during butchering appeared to be a prerogative for the hunters and butchers (Abe, 2005). The tendons were often removed and chewed immediately during the butchering process by the Evenki (Abe, 2005). The Tangzigou hunters could have easily accessed the PH1 once the long tendons along the metapodial and phalanges were removed.

Abe's (2005) ethnoarchaeological studies of the Evenki enhance our understanding of the Tangzigou assemblage by providing examples of the human behavior not related to maximizing net caloric return. The Evenki hunters live in a small group (less than ten people)

in a non-marginal environment and stay largely isolated from other groups (Abe, 2005).

They differ in several aspects of hunting and butchering behavior from other hunter-gatherer

groups, such as the Hadza, !Kung, and Nunamiut (Table 3.3; Abe, 2005). For instance,

animals were always transported as a whole carcass without discarding the low-utility part on

the butchering site (Abe, 2005). This applied both to the small musk deer and the larger

reindeer (Abe, 2005). Abe (2005) argued that the custom of non-preferential transportation

of the animal carcass in the Evenki stemmed from beliefs in animal ceremonialism. Even

though it was less efficient to transport the whole carcass, the Evenki hunters still did this to

pay respect to the hunted wild animals (Abe, 2005). During and after butchering, the Evenki

kept the whole skeletons as intact as possible and protected them in a secure area to prevent

from scavenging (Abe, 2005). Because their prey was abundant, it was the quality of the

meat that was more important than the quantity (i.e., economic utility of a carcass) to the

Evenki hunters (Abe, 2005). The Evenki's order of carcass part preference showed negative

linear relationship with Binford's utility index (GUI) that is based on the edible meat quantity

(Abe, 2005).

If there were hunter-gatherer groups like the Evenki in the past, it is apparent that it would be

difficult for the archaeologist to infer the cultural meaning of the whole carcass transport and

the preference of certain body parts. Tangzigou people could have been involved with

similar hunting and butchering activities to those seen among the Evenki. The marrow in the

phalanges could have been preferred for its quality and people could have not minded

spending time to process such bones when other resource was abundant.

Table 3.3. Difference in foraging behavior among contemporary hunter-gather groups (after Abe, 2005; her table 6.57)

	Nunamiut (Binford, 1978)	!Kung (Yellen, 1977a, b)	Hadza (O'Connell et al., 1988)	Okiek (Marshall, 1991, 1994)	Evenki (Abe, 2005)
Butchery					
On-site filleting	X		X		
Filleting in residential camp		X		X	X
In situ consumption	X	X	X		X
Transport decision					
Preferential transportation	X	X	X		
Whole-carcass transportation				X	X

3-7. Conclusions

It is important to measure the level of subsistence stress from zooarchaeological assemblages because it can provide information on seasonality and resource intensification. Therefore, the significance of developing accurate methods of measurement cannot be overemphasized. Broken phalanges have been widely used as an indicator of nutritional stress of the prehistoric people due to the low caloric return rate of the phalanges. However, our experimental studies and ethnographic data of the contemporary hunter-gatherer groups indicate that the broken phalanges from Tangzigou in and of themselves cannot be taken as evidence of resource stress. The phalanges, especially the PH1s, do not require substantial amount of processing time. A few hammerstone blows were sufficient to break open the PH1s which then gave easy access to a spoonful of marrow. Marrow from the phalanges could have been preferred for its taste and soft texture even during the period when resource

was not scarce. The digital cushion in the hoof is likely to have been a good source of fat and the phalanges could have been processed while accessing the digital cushion.

Although there is a general pattern in the hunter-gatherer groups to maximize the caloric return rate, we cannot assume that all of the foraging behavior is constrained by the nutritive value of the carcass body parts. Broken phalanges can be an evidence of resource stress only if other archaeological signatures also suggest resource scarcity, e.g., intensive processing of the higher-utility bones. Otherwise, intensively processed phalanges alone do not support the argument of nutritional stress during the time of site formation.

Chapter 4

Documenting natural wear on antlers:

A first step in identifying use-wear on purported antler tools

Authors: Jin, J., and Shipman, P.

4-1. Introduction

"Bone tools" is a general term that refers to the tools made of animal hard tissue, such as bone, antler and ivory. The expedient or *ad hoc* use of these hard tissues as tools has a long history that provides fascinating insight into hominin behavior. The earliest bone tools – which *Australopithecus robustus* probably used for extracting tubers (Brain and Shipman, 1993) or termite foraging (Backwell and d'Errico, 2008) – are found from Plio-Pleistocene deposits in South African cave sites. Morphologically different bone tools, showing flaking and use-wear, have been identified from Olduvai Gorge in Tanzania and may have been used as anvils and cutting implements (Shipman, 1989) or hammers (Backwell and d'Errico, 2004). These earliest bone tools, however, are not the product of formal manufacturing techniques; they were not deliberately cut, polished, and/or carved for a particular use (Henshilwood et al., 2001; d'Errico et al., 2003; Backwell and d'Errico, 2004).

Formal bone tools are found from Middle Stone Age sites in Africa (~90 ka), but only after ~50ka do bone tools became a significant part of human technology (McBrearty and Brooks, 2000). The proliferation of bone tools during the Upper Paleolithic/Later Stone Age is one of the archaeological signatures of modern human behavior (Klein, 2000; McBrearty and

Brooks, 2000; Bar-Yosef, 2007; Klein, 2008). Thus, the importance of documenting and accurately identifying bone tools and pseudotools cannot be overemphasized.

Unfortunately, non-human taphonomic processes can produce pseudotools that are morphologically similar to human-made tools. Simple expediency tools made opportunistically on naturally broken bones can be reliably identified by careful study of use-wear and patterning in the distribution of wear on the purported tools and then comparing those features to those on experimentally made and used bone tools (Backwell and d'Errico, 2001). Identifying antler tools poses a still more difficult problem. While bones are not exposed until the animal dies, antlers are exposed to various environments and are involved in different activities prior to the death of the deer. For example, deer often rub their antlers against bushes and tree bark which leaves scratches on the antlers. Therefore, it is crucial to document natural marks on antlers from those produced by human modification and/or use in order to distinguish between real and pseudotools. The purpose of this paper is 1) to provide information on antler development and physiology to understand the deer behaviors that might leave natural modifications and 2) to document natural modifications on antlers to use as a comparative sample in further studies to assess purported antler tools.

4-2. Antler tools

Antler tools have been reported from various archaeological sites throughout the world except from prehistoric sub-Saharan Africa where deer are not native. Numerous antler tools are found at the Aurignacian and Magdalenian sites in Europe (Pokines, 1998; Riedel et al., 2004; Bar-Yosef, 2007). Antlers have been used continuously during the Neolithic and

later. Heavy duty hafted burrs in the Late Neolithic through the Bronze Age throughout

Hungary (Choyke and Schibler, 2007), worked antler tools from the prehistoric Canadian

Arctic (LeMoine, 1997), and composite combs from the Roman period (MacGregor and

Currey, 1983) are examples.

Is there any advantage to making tools with antler rather than bone? The composition of the

hard bony antler is not very different from other bones: in dry weight, 60% inorganic (mostly

calcium and phosphorus) and 40% organic (primarily collagen) (Rajaram and Ramanathan,

1982). Despite the similar composition, mechanical properties of antler are not the same as

those of bone. MacGregor and Currey (1983) and Currey (1999) found that the amount of

work to break, a good indicator of impact resistance, differs significantly in antlers and

bones. Antler need about two to three times greater work to break than the bone; MacGregor

and Currey (1983) found the work of fracture to be 17540 Jm^{-2} for antler and 6468 Jm^{-2} for

bone.[1] This means that antler will undergo more plastic deformation before breaking than

bone (Figure 4.1). It is probably this tough and resilient characteristic that gives antler an

advantage over bone as a raw material for particular types of tools. For example, the

resilience of antlers makes them useful as batons in flint knapping (Bixby, 1945).

Antler also differs significantly in its material properties from stone. Pokines (1998)

replicated the Lower Magdalenian antler projectile point and threw the spearpoints at a dead

animal target. His experiments showed that antler projectile points had higher durability and

longer use life compared to stone points. However, the durability of an antler tool is offset

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[1] Jm^{-2} refers to joule per square meter. One joule is the amount of work required to move an object by a force of one newton through a distance of one meter.

by the longer manufacturing time. Antler cannot simply be flaked into a point as stone

can. Because of the toughness of antler, modern researchers usually soak antler in water for

a couple of days before attempting to work it (MacGregor, 1985; Pokines, 1998).

Figure 4.1. Stress-strain curve for bone and antler. Stress is the force applied in a given area and strain is the proportion of change due to applied force. The area under the curve is the amount of work required to fracture the material (after MacGregor, 1985).
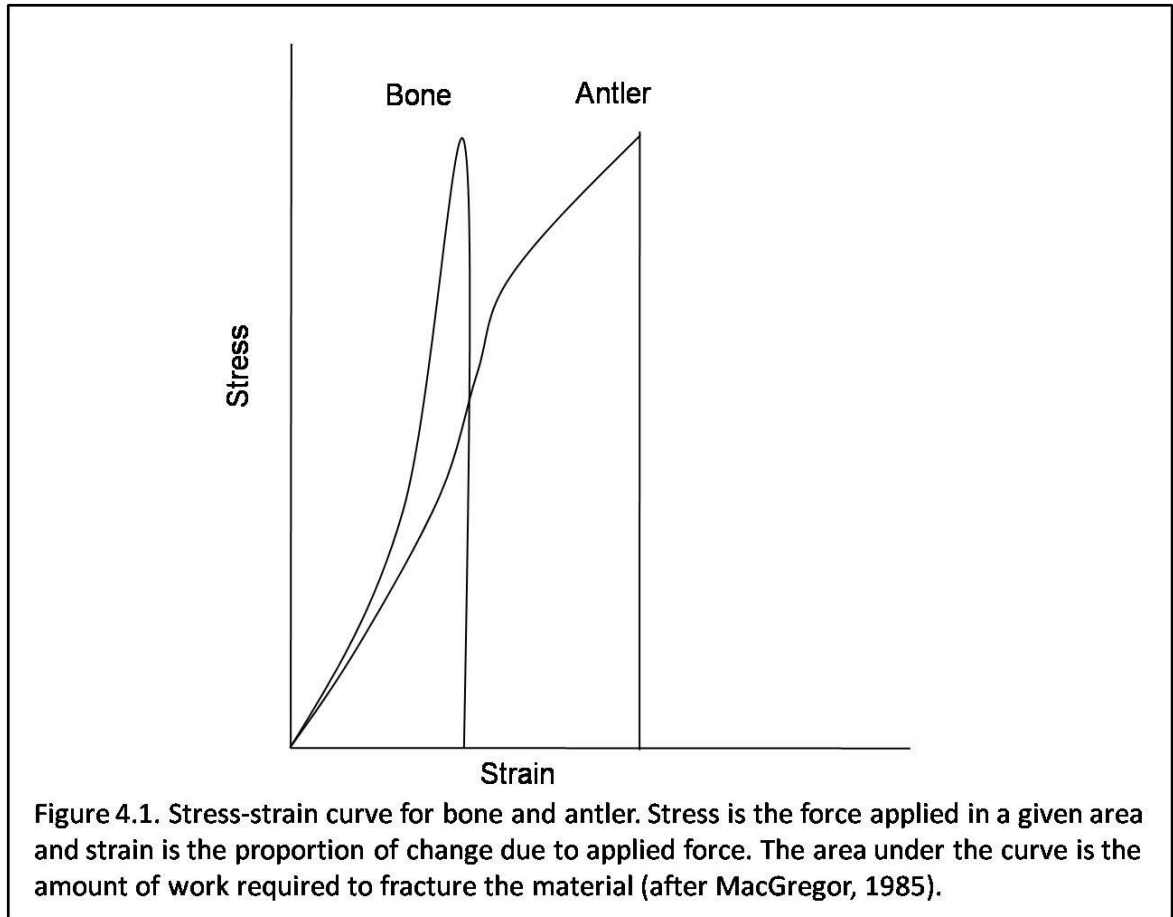
4-3. Recognizing Antler Tools

Most research on antler tools has focused on the use-wear created from different activities,

e.g. hide processing and piercing, through experimental studies. Riedel et al. (2004) argued

that the Stone Age/Bronze Age antler axes from Hannover, Germany were used primarily for

woodworking based on Scanning Electron Microscope (SEM) analysis of apparent use-

wear. Neolithic and Chalcolithic antler tools from Europe were examined under the reflexion

microscope (Legrand and Sidéra, 2007). The researchers suggested that the antlers were likely to have been used in hide scraping and fresh bark working based on their microscopic resemblance to experimental tools used in these tasks. A similar use-wear analysis of the Mesolithic antler tools from the Netherlands concluded that the antlers were used mostly for hide working (van Gijn, 2007).

Use-wear analysis of experimental antler tools undoubtedly provides valuable information on the modification of antler surfaces by human activities because the surfaces can be documented *before and after controlled use*. Would similar use-wear analysis be sufficient to support or refute the existence of antler tools from archaeological sites? Unlike specimens in experimental studies, archaeological antlers do not provide any information about the "before" stage. Even if the modifications on the archaeological antlers are similar to those of the use-wear created, for example, during hide scraping, the possibility remains that natural modification of antlers could mimic human use unless antler modification via deer behavior is thoroughly documented.

However, comparing use-wear on archaeological antlers to that on antlers of known taphonomic history is an important step in distinguishing between possible agents of modification. Use-wear studies must compare unknowns (archaeological specimens) with a reference collection of knowns (experimentally modified specimens). The credibility of a claim that the unknown matches a known depends upon 1) the extent to which diagnostic aspects of the use-wear can be documented on the reference sample and 2) the breadth and variety of knowns with varied taphonomic histories to which the unknowns have been

compared. Conclusions must take the implicit form: "Within the reference sample consulted here, taphonomic agent X produces modifications most similar to those on the unknown." Similar problems occur in distinguishing various taphonomic changes on bones from the anthropomorphic modifications, a topic that has been extensively studied (e.g., Backwell and d'Errico, 2001; Shipman and Rose, 1983a; Shipman, 1989; Behrensmeyer et al., 1986; Blumenschine and Selvaggio, 1988). The crucial difference with purported antler tools is that antlers can be and are modified significantly not only after the death of the deer but even before the animal dies.

Except for some indisputable antler tools, most purported antler tools need closer examination to confirm their nature as human-made tools. An important aspect of assessing purported antler tools is understanding the natural behavior of the deer, which rubs its antlers against bushes and trees, and produces distinctive marks on the antlers. Further, the antler tips get highly polished — taking on a shiny, smooth or glassy surface reminiscent of that produced by human use – through natural deer activity. In many publications, antler tools are described simply as being "highly polished" without further description and without adequate images; we propose that purported antler tools cannot be accepted as humanly modified without more investigation. A systematic method is required to distinguish natural marks from human induced marks.

Olsen (1989) demonstrated this point amply in her SEM examination of 110 pairs of uncast antlers from 11 deer species to document the pre-casting marks that can mimic wear on antler tools. She found that abrasion, polishing, marring, and terminal impact fractures are

widespread natural modifications and their distribution on the antler is distinguishable from that of human induced modifications. In particular, Olsen (1989) reported that the most prevalent modification on the antlers was polished tines, which she found on all of her samples. Despite the importance of Olsen's excellent study of the natural marks on the antlers, not much research has been done on this subject since her work.

In this project, we followed on Olsen's work with an intensive study of naturally modified antlers of a single species, the white-tailed deer (*Odocoileus virginianus*). We have established a large comparative collection (N = 347 antlers) which can be used to assess the nature of purported antler tools in future studies. Here we provide more detailed descriptions and quantification of natural modifications to antler using a larger sample than any previous work of which we are aware.

4-4. Antler development and physiology

We review here the deer behaviors that modify antlers. These behaviors are closely related to the antler development cycle and its physiology.

Antler is the principal morphological character separating deer (Family Cervidae) from other ungulates (Yahner, 2001). All male deer, except the Chinese water deer (*Hydropotes*), grow antlers[2]. In reindeer and caribou, both males and females have antlers. Antlers differ anatomically and developmentally from the horns of bovids (Family Bovidae) and pronghorns (Family Antilocapridae, of which the only living member is *Antilocapra*

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[2] *Moschus*, the musk deer, male does not grow antlers. However, the classification of the genus *Moschus* is debatable. Some researchers group *Moschus* with cervids but others with the Family Tragulidae. Here we followed the latter classification.

americana). First, antlers are shed annually and a new set grows back, while horns are permanent structures[3] that stop growing after maturation. Second, while horns start growing as a separate bone and later fuse to the skull, antlers grow directly from the skull.

Most deer are seasonal breeders with their physiology being sensitive to the day length, except for that of the tropical species. We used seasonal deer as our model in the following discussion. Most of the information on antler development and physiology summarized here is from Brown (1990), Goss (1983, 1985), and Whitehead (1993).

Antlers grow from the pedicle, a projecting bony structure on the frontal bone (Figure 4.2 and 4.3)[4]. The pedicles start to develop immediately after the fawn is born; antlers begin to grow within the fawn's first year, in the spring. The main beams grow first from the tip of the pedicle and once this main structure is formed, then the small branches (tines) develop. Rapid growth in length and width happens in the summer. Antlers reach their maximum size after three to five months.

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[3] The pronghorn sheds the outer keratinous sheath of its horns annually but does not shed the bony horn itself.

[4] The pedicles are usually short except the ones of muntjac, a small-size deer native to the South and Southeast Asia. Muntjac antlers are shorter than the pedicle.

Figure 4.2. Skull of a male deer
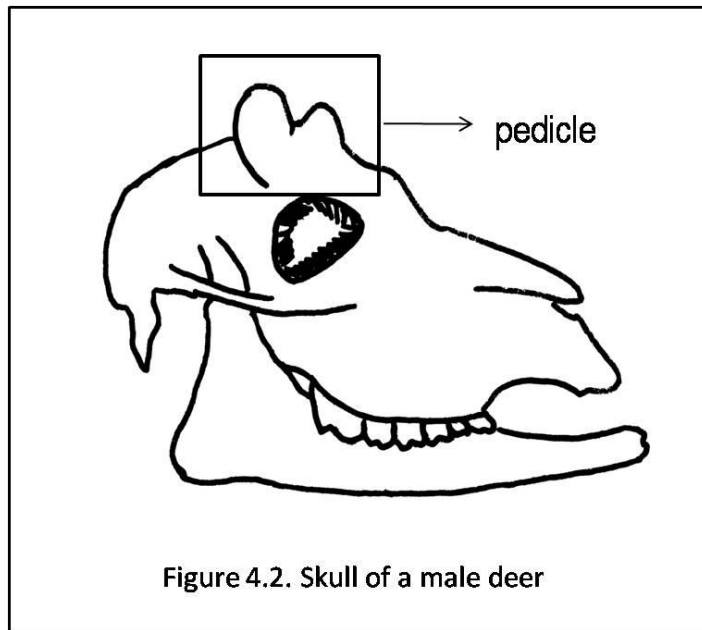
During the period when antlers grow in length, they are covered with skin and hairs called velvet. Velvet is richly vascularized in order to supply nutrition to the fast-growing antlers. Velvet-covered antlers are also highly innervated and thus very sensitive which permits buck to learn their own antler morphology. During this stage, antlers are not bony but are still soft cartilage, which is later replaced by bone. Because of the extensive innervation of cartilaginous antlers, deer protect their antlers from blows and avoid physical fighting during this phase. If the deer hits its cartilaginous antlers on something hard, the antlers are likely to be deformed and the new shape will be maintained until they are shed (Figure 4.4). At this stage, deer confront each other by standing upright on their hindlegs. Once the antlers are fully grown, blood supply to the antler is gradually cut off starting just above the pedicle. At the same time, cartilaginous antlers begin to mineralize by endochondral ossification. Trabecular bone forms first and then the trabeculae are gradually filled with compact bone, which leaves no room for blood vessels. Hard bony antlers have

many grooves, in which blood vessels lie, surrounded by extra bone. Special bumps called "pearls" (Figure 4.5) are formed, most commonly on the beam and distal tines but not on the tips.

Figure 4.3. Terminology for the different parts of the antler
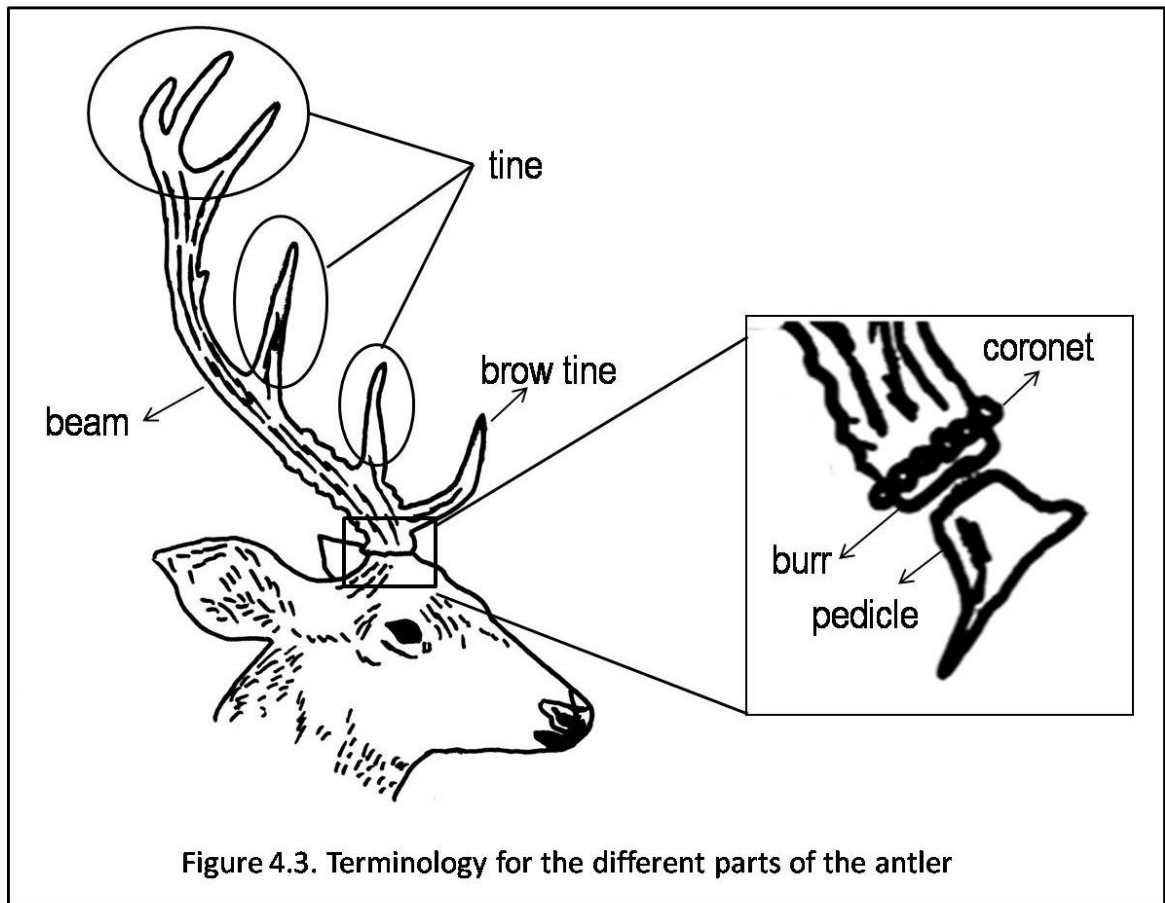
Figure 4.4. Deformed antler tips. (a, b) Bump on tine, (c) flattened tip, (d) rounded tip, (e) whole antler deformation. Scale bar = 5 cm.

Ossification occurs within a month, a period during which large amounts of extra minerals are required. The buck use the minerals already stored in their skeletons, then replace those minerals through the diet. Buck respond to the decrease in daylight in the fall with elevated testosterone levels. The testosterone shuts down the blood supply to the antlers and velvet at the junction of the pedicle and burr, starting velvet necrosis. When the velvet dries and peels off, the light-colored, bony antlers are exposed.

Velvet is naturally removed from the antlers during a few days in which buck rub their antlers on vegetation to get rid of the drying velvet. This behavior is likely to leave marks on the antlers and may contribute to the shiny and highly polished surface of the beam towards the tip.

Figure 4.5. "Pearls" on the proximal beam. Scale bar = 3 cm.

Testosterone levels remain high through the late fall and the early winter during the rut. Male deer use their antlers in intrasexual competition in several ways. First, antlers can be a visual weapon or display object. In many cases, male deer compare each other's antler size by posturing without any physical contact. If the one male has larger and more complex antler morphology, the other deer retreats. If neither of them backs off, antlers can be used in a second way, as actual weapons. Two male deer lower their heads and lock their antlers to pull against and wrestle with each other. Tips are easily broken off during the fight. Third,

antlers are also used to mark territories. Deer rub their antlers against bushes, foliage, and

tree bark in a manner similar to the behavior used to remove drying velvet. Although the

exact purpose of fraying and scoring at this stage is still debated, this behavior leaves visual

marks on the vegetation and scent marks using the gland on the frontal bone. Another source

of natural modification to antlers occurs when deer chew on each other's antlers in

nonaggressive situations (Barrette, 1985; Bowyer, 1983). All of these activities are highly

likely to damage the antlers.

After the rut, the male deer carries his bony antlers for another couple of months. At this

stage, the bony antlers are not as hard as they were in the fall but drier and more

brittle. When the day length increases in spring, testosterone levels plummet in male

deer. Consequently, the already-fragile antlers detach from the pedicle. In most deer species,

new antler growth cycle is initiated immediately after shedding the old antlers[5]. The shed

antlers disappear quickly because they are a source of calcium and phosphorus that rodents

and other artiodactyls ingest by gnawing (Sutcliffe, 1973). Naturally shed antlers can be

easily distinguished from the artificially cut ones if the proximal portion of the antler is

preserved since the coronet and burr are present in naturally-shed antlers (Figure 4.6).

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[5] Reindeer and caribou shed their antlers in the beginning of the harsh winter. Their antler regeneration is
delayed until the spring when the food resource is more abundant.

Figure 4.6. (Top) Naturally-shed antler, (bottom) artificially-cut antler. Scale bar = 3 cm.

4-5. Sample and Methods

A total of 347 specimens of white-tailed deer (*Odocoileus virginianus*) antlers collected

between 2000 and 2008 were obtained through the Penn State Deer Research Center. Most

of the antlers were artificially removed from the Penn State deer herd prior to the annual

onset of mating season to prevent injury from male-male fighting.

An advantage of this study sample is that -- compared to the naturally-shed antlers -- these

artificially-cut antlers show fewer marks and less polish because of their earlier removal from

the deer (Don Wagner, the Deer Manager at the PSU Deer Research Center, personal

communication). Thus this sample exhibits a conservative level of natural wear. If these premature-removed antlers show a high degree of polish, for example, we can safely assume that the naturally-shed antlers would show equal or more polish. An additional advantage of the current sample is that post-casting taphonomic modification was eliminated. After removal, all the antlers were kept in an indoor storage box and protected from other taphonomic agents, such as weathering, sedimentary abrasion, trampling, or rodents.

Each specimen was examined first with naked eyes under bright light and scored for gross modifications, including scratches, polish, and deformation. Scratches are defined here as linear grooves cut into the surface of the antler. Polish – which does not imply human agency – is here defined as an area with a smooth, shiny surface that shows little roughness or irregularity. Deformation is defined as an alteration of the shape of the antler due to a healed injury to the antler during its cartilaginous stage.

Scratches and polish

We documented the location and extent of polish and orientation of scratches because similar data have been useful in differentiating use-wear on expedient bone tools from natural modifications (Backwell and d'Errico, 2008; Brain and Shipman, 1993; Shipman, 1989). Expedient bone tools show polish only at the working end and show non-random directionality of scratches according to the use of the tool.

We measured the location and extent of the heavily scratched and highly polished surface of each antler using dental floss. We also recorded the orientation of the scratches for thirty

representative antlers by defining a sampling area of heavy scratching 2 cm by 0.5 cm on each antler. Close-up photographs were taken for each sampling area using a macrolens. Within that area, we measured the angle of each visible scratch relative to the mid-axis of the main beam using image processing and analysis software, Image J (Figure 4.7a).

Deformation

Antlers were scored for the presence or absence of deformation and we noted whether the corresponding antler in the pair also showed deformation. Each deformed specimen was also described qualitatively.

4-6. Results

Scratches

Scratches occur on 72% (N = 250) of the specimens (Figure 4.8). Scratches are very shallow and difficult to see if the antler surface is very shiny, but on most specimens, scratches are numerous, distributed all over the antler, and apparently randomly oriented. The box plots of Figure 4.7b show orientation of striations in thirty specimens that clearly demonstrate the random distribution of the scratches.

Despite the random orientation of scratches in our sample, there were consistent patterns in the distribution of scratches on these antlers. In every antler, the surface that faces laterally in life was more intensively scratched than the medial-facing surface. Further, within the lateral surface, most scratches occurred on the superior half of the antler while the inferior half is

usually shiny and smooth (Figure 4.9). This difference in mark distribution is probably

related to the angle at which the antler is attached to the deer's skull, which in turn limits the

angles at which the antlers may contact other objects such as foliage, bushes, and tree bark.

This pattern was consistent in our sample. However, deer with different antler morphology

may show different patterns of natural wear.

Figure 4.7. Image analysis of the scratches on the antlers. (a) Measuring the angle of each visible scratch relative to the mid-axis of main beam using Image J, (b) orientation of striations on thirty specimens. Each boxplot represents one specimen.
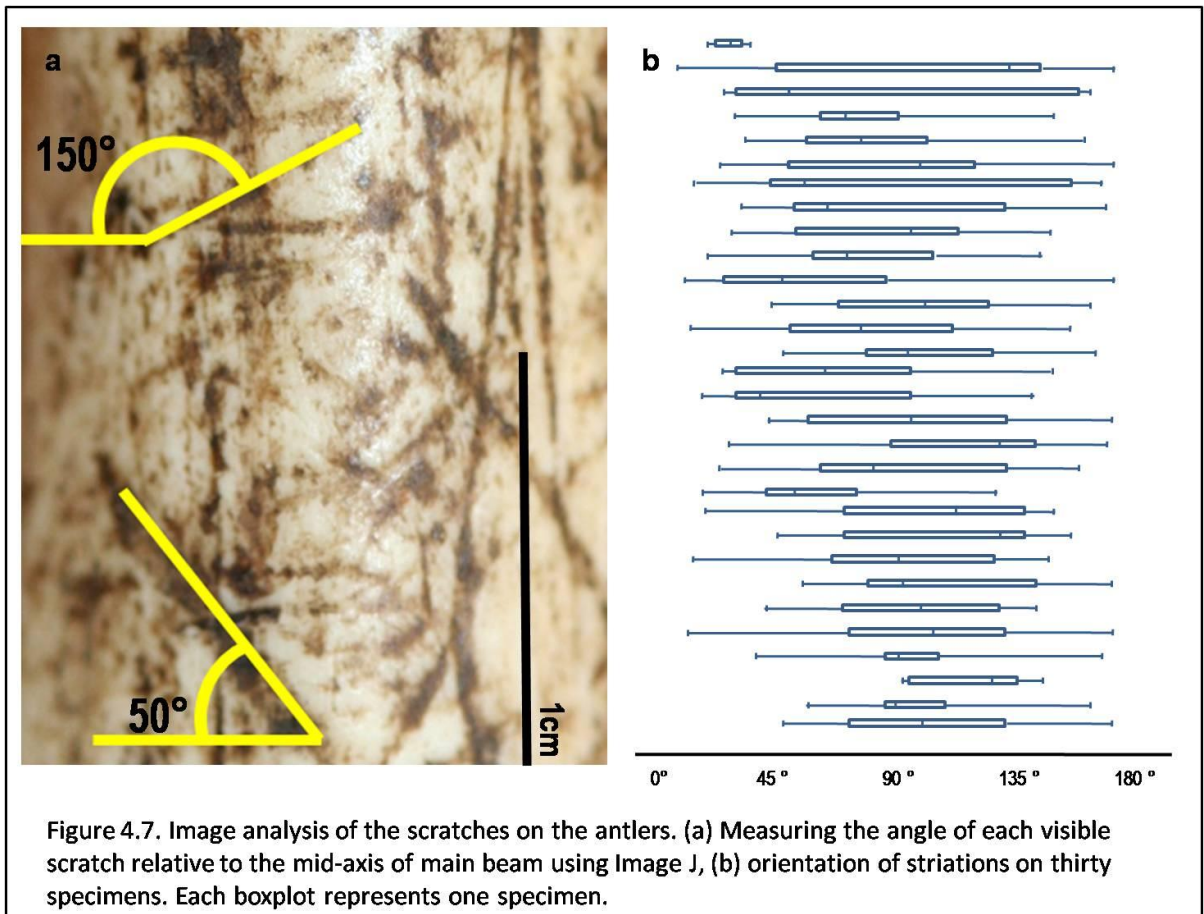
Polished surface

Every specimen in our sample (N = 347) had polished or shiny tips (Figure 4.10). On average, the area of polish reaches 4 cm down from the tip on the longest first tine. Some of the specimens show polish on the entire tine. For all other tines, polish occurs on the top ~1.5 cm area. This pattern was true even on the brow tines, where the pearls occur closer to the tip. Because some specimens still had dried velvet covering the tip, we were able to peel back this dried velvet to expose antler tips that had never been in contact with the environment. Importantly, even these newly exposed tips were shiny and smooth, proving that the apparent polish on antler tips is not the result of contact with environmental substances or of human use of the antler. The smooth and apparently polished surface of antler tips is their natural morphology.

Figure 4.8. Naturally produced scratches on the antlers.

Figure 4.9. White-tailed deer antler. Note the distribution of the scratches. Most of them are concentrated on the top half (dorsal aspect) and the bottom half (ventral) is shiny with no marks (left drawing after Goss, 1983). Scale bar = 1 cm.

Figure 4.10. Antler tip with smooth and shiny surface. Scale bar = 1 cm.
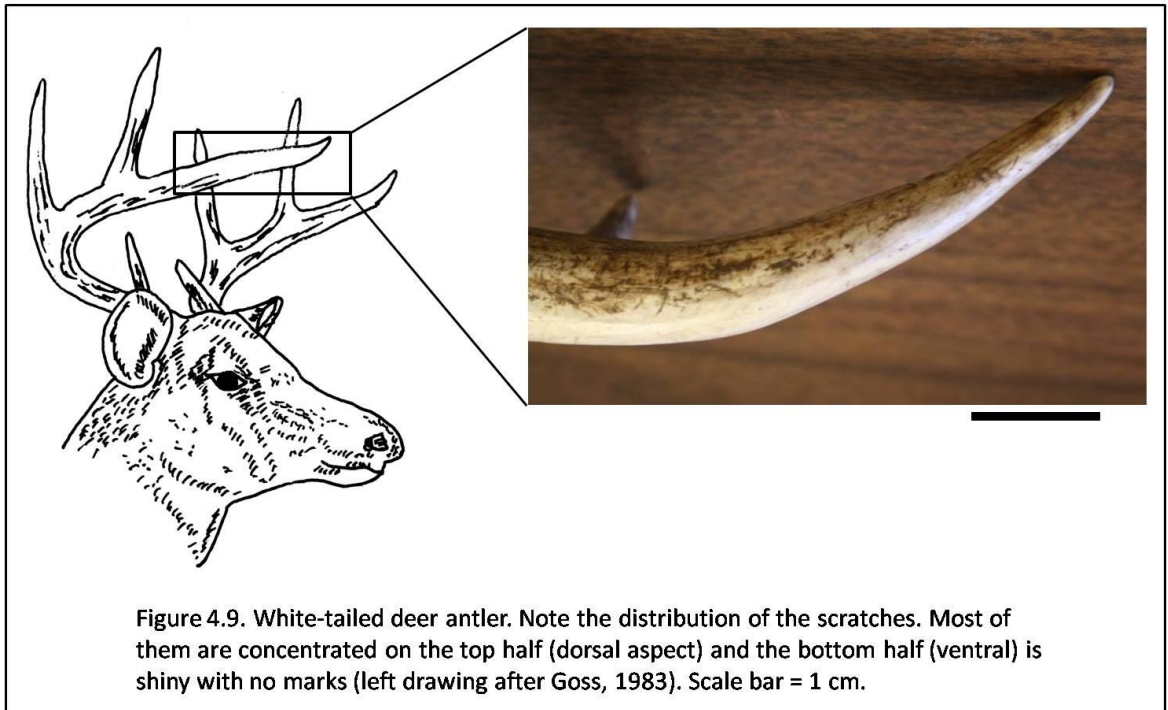
Among our specimens, 39% (N = 134) show deformation (Table 4.1; Figure 4.4), such as

bumps on the beam or tip, or flattened or rounded tips. These deformations result from life

activities while the antlers were still cartilaginous. Deformation occurs most frequently on a

single tip or tine but in some cases multiple tines from a single individual are deformed.

Table 4.1. Antler deformation. See Figs. 4.4 and 4.11 for detailed morphology of each type.

Type of deformation	Number	%
Beveled tip	37	27%
Bump on tine	44	33%
Flattened tip	29	22%
Rounded tip	14	10%
Whole antler deformation	10	8%
Total	**134**	**100%**

Breakage: Beveled tips

Beveled tips occur in 10% (N= 35) of the total specimens in our sample (Figure 4.11).

Observations of living deer herds show that antler tips break in this way during natural use

(Don Wagner, personal communication). All but two beveled tips in our sample were also

polished. Olsen (1989) reported a similar finding and concluded that fractured tines

commonly became polished and abraded through natural use subsequent to the fracture.

Figure 4.11. Beveled antler tips. (Left) naturally beveled tip, (right) beveled tip antler excavated from Tangzigou. Note the similar morphology.
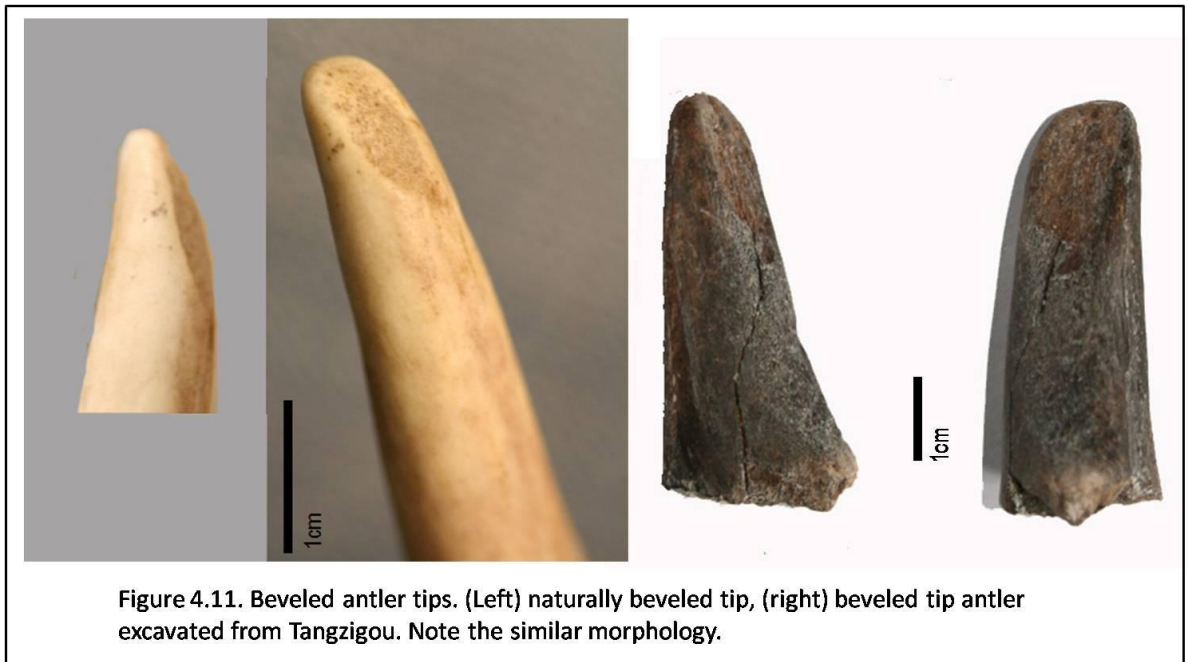
A pair of antlers from a single individual in our sample supports this scenario. Antlers are normally symmetrical but, in this pair, the first tine of the right antler is about 5 cm shorter than the one on the left. The shorter tine ends in a beveled and shiny tip (Figure 4.12). The tip of the right antler was broken during life and became smooth and shiny through natural use. Therefore, we maintain that the existence of a beveled tip alone cannot be taken as evidence that an object is a humanly-made tool.

Figure 4.12. Fractured and healed antler tip. Note the different length of the left and right first tines. Scale bar = 10 cm. Right image is the close-up of the circled area.
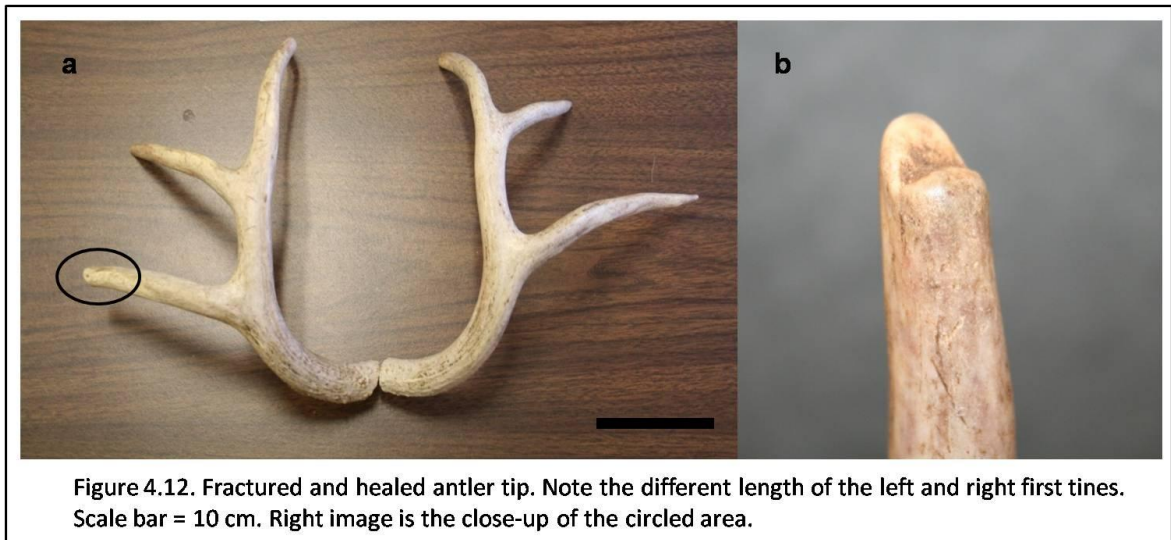
Our sample also includes two specimens that have very fresh terminal fractures with rough or irregular fracture surfaces (Figure 4.13). We believe that these were made very shortly before the antlers were removed and had not yet become polished through natural wear.

Figure 4.13. Obliquely fractured antler tip. Scale bar = 1 cm.
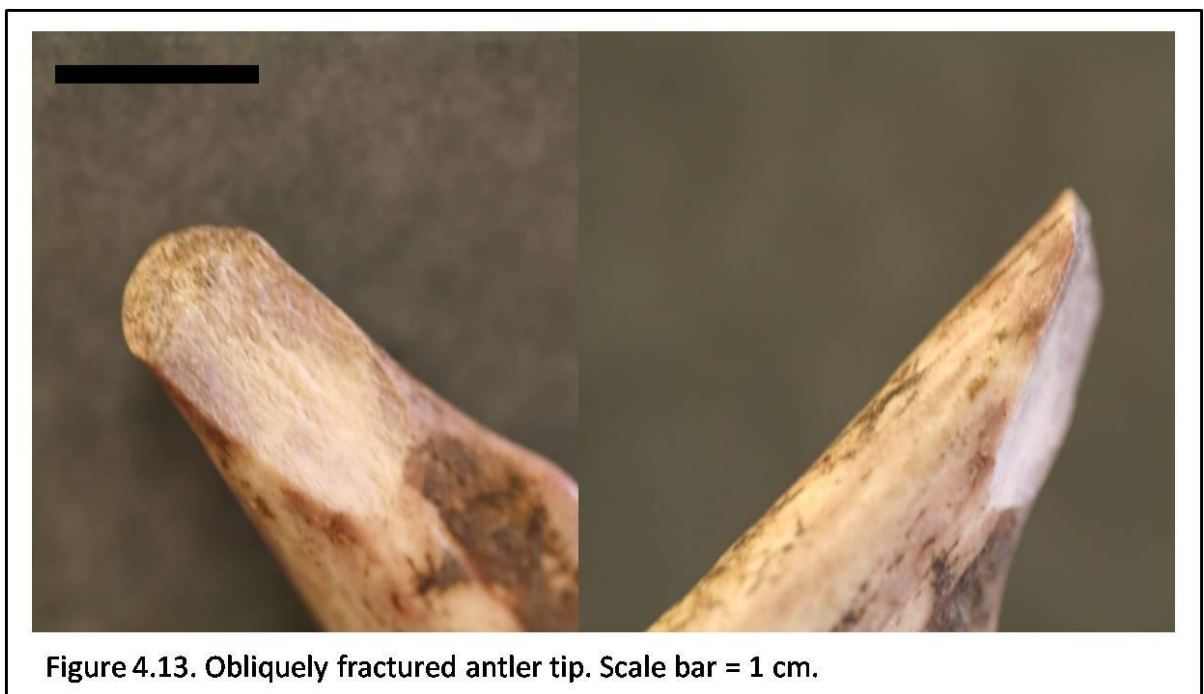
Terminal fractures with oblique breakage surfaces are also frequently reported in elephant tusks. Broken elephant tusk tips are commonly found in natural elephant habitats and also in numerous archaeological/paleontological sites in Europe and North America (Haynes, 1991). Elephant tusks break easily not only when the elephants are engaged in aggressive interactions but also during the normal activities such as manipulating vegetation or breaking up sediments and termite mounds for minerals (Haynes, 1991). After the tip is broken, the fracture surface becomes smooth and worn down due to the constant use of the tusk (Haynes, 1991). Although the elephant tusk is less resilient than antler and is thus easier to break (Rajaram, 1986), the existence of beveled and polished fractures in elephants tusks is pertinent because elephants and deer use their tusks and antlers somewhat similarly. The process of tusk breakage and polish is similar to natural behaviors and wear that we have argued produce beveled and polished tips on antlers.

4-7. Discussion

Among the various modifications and deformations found on the natural antler sample, three types require further discussion because they have been commonly used as criteria to validate the claims that a particular object is an antler tool: the polished tip; the beveled tip; and the fractured surface.

For example, "polished antler tools" have been reported from several archaeological sites, including Zhoukoudian Upper Cave (Pei, 1939; cited in Norton and Gao, 2008b) and Ortvale Klde rockshelter from southern Caucasus (Adler et al., 2006). Similarly, antlers excavated from the 8,800 year old archaeological site Tangzigou, Yunnan, China, in the 1980s were

claimed to be antler tools (Zhang, 1992) based on their polish, beveled tips, or breakage. These specimens are displayed in the local museum as tools and are the subject of ongoing study by one of us (JJ). The existence of beveled tips on antlers has also been taken as evidence that antlers were used in hide scraping and wood working in Northern Europe during the Early Mesolithic (David, 2007).

Polished Tips:

The polished tip is ubiquitous among antlers in our study and that of Olsen (1989). Our observation that antlers with adhering velvet, when cleaned, showed polished tips indicates that this polish is merely the natural texture of antler tips. Clearly the existence of a highly polished tip cannot be taken as adequate evidence that an antler was used as a tool.

Beveled Tips:

Beveled and often polished tips occurred in 10% of our sample; therefore a beveled and polished tip, though not common, cannot be taken as firm evidence of human modification. However, we cannot rule out the possibility that humans found and chose to use tips that were naturally beveled, perhaps because such tips offered a larger surface area for working. For example, rods of bone and ivory -- but not antler (Haynes, 2002) -- found with the Clovis points from North American sites frequently show the beveling on the ends (Lyman et al., 1998). The abundance of bones with beveled tips associated with Clovis points that were clearly manufactured suggests beveled cylindrical objects may have been desirable or useful objects. Naturally beveled antler tips could have been used by humans in various activities,

but we anticipate difficulty in finding rigorous criteria that will distinguish humanly-used from deer-used beveled antler tips.

Fractured surfaces:

Though antler tips with beveled fractures and polish are common in naturally modified antlers, we did not observe any transversely fractured antlers in our sample, nor did Olsen in hers (1989). Naturally-shed antlers have transverse surfaces at their proximal end, but these are part of the normal burr and coronet structure and cannot be mistaken for a deliberately cut surface. Nonetheless some archaeological sites have yielded antler pieces that terminate proximally in transverse fractures, not in burrs or coronets. In such cases, the following questions can be raised: Were the antlers artificially cut? If so, how were they cut?

One example is a purported antler tool found in a Late Pleistocene site in Yukon with a smooth transverse break (Harington and Morlan, 1992). Unfortunately, this possible antler tool was badly eroded by an unknown taphonomic process so that the texture and any manufacturing marks upon the original fracture surface were destroyed. Other examples come from a fossil bone assemblage excavated by one of us (JJ) and colleagues from the archaeological site Tangzigou, in Yunnan province, China. Thirty-two out of 93 antlers from Tangzigou (34%) are broken transversely on the main beam, close to the pedicle (Figure 4.14).

Studies of bone breakage suggest that transverse fractures of long bone occur under particular taphonomic conditions. Although green bones have a strong tendency to break in a

spiraling course, particularly if subjected to twisting force, long bones that are dry and permineralized – in which the collagen fibers have broken down -- have a tendency to break transversely (Johnson, 1985; Villa and Mahieu, 1991). These observations suggest that the same taphonomic conditions might be required for antler to break transversely unless there was human intervention.

Figure 4.14. Muntjac antler from Tangzigou. See the transversely fractured surface.

Transverse breakage was completely absent in the natural sample studied here and in Olsen's sample. The presence of multiple examples of transverse fractures in antlers from the Tangzigou assemblage could be explained by one of four different hypotheses.

First, such fractures might occur naturally during or after the rut but do not appear in our sample because these antlers were cut from the deer prematurely. However, Olsen's naturally-shed sample did not contain any transversely broken antlers either, suggesting that this hypothesis is not correct.

Second, the antlers from Tangzigou might break differently from those in our sample because they are derived form a different cervid species. This hypothesis could be tested by additional large-scale studies of naturally-shed antlers from Asian deer.

Third, the antlers in the sample studied here might develop transverse fractures in time once they are weathered, dried, and permineralized. If this hypothesis is correct, then the Tangzigou antlers with transverse fractures will show more signs of weathering and drying than those antlers which do not show transverse fractures. Preliminary data on the surface condition of these specimens do not suggest that the Tangzigou antlers with transverse breakage are more heavily weathered than antlers from the same site lacking transverse breaks.

Fourth, humans at Tangzigou may have deliberately cut or broken the antlers transversely. There is no experimentally known mechanism for reliably producing a transverse fracture on

fresh antler. If the Tangzigou antlers were cut or scored and snapped, as bone can be during

bead manufacture, then the well-preserved fracture surfaces should show microscopic

evidence of the manufacturing (cutting) process.

A further issue is pertinent. Sharp tools easily cut antler, but none of the stone tools from

Tangzigou is made of raw materials like chert or obsidian that hold extremely sharp edges.

Thus, if the transverse fractures were produced by humans at Tangzigou, either the tools with

which they cut the antler have not been recovered or they used a method not yet considered.

Additional studies and experimental work are needed before we can confirm or refute any of

these four hypotheses.

Microwear analysis

Examining specimens under a high-powered microscope and SEM (Scanning Electron

Microscope) has been widely and successfully used to confirm or refute the identity of

purported bone tools since the 1980s (e.g., Potts and Shipman, 1981; Shipman and Rose,

1983a; Arndt and Newcomer, 1986; Olsen, 1988; Olsen and Shipman, 1988; Shipman, 1989;

Backwell and d'Errico, 2001). If microscopic wear from natural deer behavior can be

distinguished from human use-wear, then such analyses will be crucial in identifying genuine

antler tools.

Various types of microscopic use wear on experimental antler tools have been already

documented (e.g., Olsen, 1989; Riedel et al., 2004: Legrand and Sidéra, 2007; van Gijn,

2007). Similarly, Villa and d'Errico (2001) examined a ~3cm long antler tip found in the

Mousterian layer from Combe Grenal, France, that had been claimed to be a projectile point due to its sharp end (Bordes, 1968). Villa and d'Errico (2001) reexamined this specimen under optical microscopy and SEM, finding no evidence of human modification. Using the same method, they also disputed the identification of some putative ivory tools by comparing the "ivory points" from the European Middle Paleolithic site to the naturally modified modern elephant tusks (Villa and d'Errico, 2001). LeMoine (1997) found purported antler tools from a Canadian Arctic archaeological site showed various combinations of polish and striation, but none of the experimentally-produced patterns of microwear she studied matched the features of the purported antler tools.

What is lacking is a large-scale study of natural antler microwear to which experimental use-wear can be compared. In our future studies, we plan to examine our sample of naturally modified antlers under the high powered microscope and SEM to document natural usage at the microscopic level. This reference sample can then be compared with experimental use documented by others and with polished tips, beveled tips, and transversely fractured antlers from Tangzigou and other archaeological sites.

4-8. Summary and Conclusions

Antler has been used as an important raw material to make tools because of its resilience. There is no question that humans deliberately modified antlers into various tools, combs, and decorative objects at some sites and some points in time. Interpretation of the less clearly modified antler "tools", however, can be complicated because not only humans but also the deer modify antlers. Deer rub their antlers against foliage, bush, and tree bark to expedite

removal of the dried velvet and also to leave scent marks. During the rut, antlers are extensively used in male-male competition. All of these activities are likely to leave traces on the antlers. Therefore, recognizing the natural marks on the antlers is a necessary prerequisite to identifying antler tools. In this study, we examined 347 extant white-tailed deer antlers. Scratches, smooth and shiny surfaces, and various deformations are the most frequently found modifications. Unless these natural marks can be distinguished from the human made marks, the nature of the purported antler tools will remain questionable.

Chapter 5
Summary and Conclusions

5-1. The nature of the Tangzigou site

Zooarchaeological and taphonomic analysis of the Tangzigou assemblage strongly suggests that Tangzigou was a butchery site rather than a residential site for the hunter-gatherers. Tangzigou people probably carried the animal carcasses up to the site probably because it was an elevated area with sparse or at least not dense vegetation in a wooded environment. Thus, the site could have served as a vantage point from which people could watch out for predators and process the carcasses. Large boulders and outcroppings of base rock on the site could have been used as carcass processing platforms.

Among the mammals studied in this study, small cervids were the most abundant group (56 % of the total NISP) followed by large cervids (24 %) and large bovids (20 %). The relative abundance of these groups can be explained in three ways that are not mutually exclusive. First, the Tangzigou abundance may reflect the actual ungulate taxonomic abundance of the living community in the Early Holocene western Yunnan. This hypothesis is difficult to test because very little is known about the distribution and population size of the cervids and bovids in Yunnan during the Quaternary. However, it can be speculated that the small cervids was more abundant than the large cervids and bovids. In general, animals with a small body size are usually more abundant per unit of area than animals with large body sizes (Hutchinson and MacArthur, 1959). Therefore, small cervids at Tangzigou may comprise of a wider variety of species than the larger cervids and bovids; for example, small-bodied deer include different species of muntjac, tufted deer, and hog deer, which will increase the

abundance of this category of animals in the assemblage. Because I focused only on the post-crania in this study, it was not possible to distinguish the small cervids into species. Second, small cervids might be overrepresented in the Tangzigou assemblage because people preferred to hunt them. It is likely that the small cervids was easier to hunt and carry than the large cervids and bovids. Further ecological studies of the modern and fossil ungulates of the western Yunnan will help clarify this issue. Third, the different proportions of small and large-sized animals at the site may reflect the difference between small game that can be consumed by a few individuals and larger game that should be taken back to the rest of the family or social group.

This third hypothesis is suggested by differences in the representation of animals of different sizes at the site. Small cervids were processed and consumed at the site, and thus are represented by all parts of the body. In contrast, the meatier body parts of the large cervids and bovids were transported away from the site to another place, probably to the residential camp. Underrepresentation of the high-utility body parts of the larger mammals from Tangzigou supports the hypothesis that Tangzigou was a butchery site. While they were butchering the large cervids and bovids, Tangzigou people snacked on the phalanges and the digital fat pad in the hoof. It is a commonly observed behavior among the contemporary hunter-gatherers to crack bones for marrow consumption and to chew tendons while butchering the carcasses. This *in-situ* consumption is considered to be a reward for the hunters.

The experiments with the modern cow and deer phalanges in this study showed that accessing and breaking the phalanges were not as difficult as it was previously thought. Tendons and ligaments surrounding the phalanges were removed easily with stone tools and the phalanges were broken only after one to two blows when they were disarticulated from other bones. After butchering the animals into smaller parts, Tangzigou people left the site with the high-utility body parts of the large cervids and bovids, leaving the small cervid remains behind. This behavioral pattern is likely to have been repeated multiple times given the high MNI of small cervids (N = 74) and the radiocarbon dates spanning only two hundred years at most. The lack of living surfaces, hearths, fire-cracked stones, and pottery also suggest that Tangzigou was a site visited temporarily for butchery with no further processing such as boiling.

Once Tangzigou people stopped visiting the site, or in between seasonal visits, the animal bones and tools were buried quickly without allowing sufficient time for the carnivores and rodents to destroy or disarticulate them. The remains were moved only a short distance downslope from the original deposition site, probably by runoff during multiple rainstorms. All the gaps between the large boulders and base rocks were filled with the sediments, bones, and artifacts. The faunal assemblage was then well preserved without any significant post-burial disturbance until they were recovered by the archaeologists.

5-2. Absence of intensification at Tangzigou

Zooarchaeological and taphonomic analysis of the Tangzigou assemblage found no evidence of resource intensification during the time of site formation. The Tangzigou long bones were

not heavily broken. Logically, people under high subsistence stress should process every bit of the within-bone nutrient, thus producing a highly fragmented assemblage with a high fragmentation ratio (Outram, 2001; Munro and Bar-Oz, 2005). If people are under nutritional stress, bones with higher marrow yield will be more intensively processed. Thus, 1) high fragmentation ratio and 2) the significant positive correlation between bone marrow yield of different bones and the fragmentation ratio have been used as evidence of resource stress and intensification (e.g., Bar-Oz and Munro, 2007; Prendergast et al., 2009). The Tangzigou assemblage, however, showed significantly low long bone fragmentation ratio compared to those from other sites and no correlation was found between bone marrow yield and the fragmentation ratio.

Although the higher-utility long bones (i.e., bones with higher meat and marrow yield) were not heavily broken, Tangzigou people intensively broke and processed the lower-utility foot bones. It is commonly accepted that heavily broken phalanges from archaeological sites are indicative of resource stress because of the longer processing time to access the bones and lower marrow yield (Binford, 1978; Jones and Metcalfe, 1988; Burger et al., 2005; Munro and Bar-Oz, 2005). Therefore the low fragmentation ratio and lack of processing of high-utility bones contradicted the intensive processing of low-utility foot bones. These contradictory data were subjected to further investigation in Chapter 3.

The experiments with modern cow and deer phalanges in this study showed that the previous interpretation of broken phalanges may not be universally applicable to all faunal assemblages. Phalanges were not more difficult to access and process than other bones.

Even though the caloric return rate is low for the phalangeal marrow, ethnographic studies have documented numerous incidents when people do not choose their diet strictly based on the quantity of the food. Marrow in the phalanges could have been preferred by Tangzigou people due to its soft texture and good taste from its high content of unsaturated fatty acid compared to other long bones (Morin, 2007: his table 3), which makes it still the most desirable marrow among the Arctic Eskimos (Stefansson, 1944). Therefore, the intensively broken phalanges can reflect behaviors in the "good time" when people were able to afford the time and effort to process delicacy for non-caloric related reasons. To Tangzigou people, phalangeal marrow may simply have been a special luxury food.

The low number of cut marks on the bones could also be explained as the result of non-intensive processing of the carcasses. If Tangzigou people did not have to remove all of the available flesh from the carcass, then there would be less chance for them to leave marks on the bones. Alternatively it might be due to the absence of sharp stone tools in the local region that are most likely to leave traces on the bones. Further experimental research is warranted on the microscopic features produced by the use of non-stone tool, such as bamboo tools.

Overall I found no evidence of resource stress at Tangzigou. Tangzigou people seemed to have enjoyed the rich natural resources including hundreds of endemic plants and animals. Intensification may not have been part of the subsistence shift process in western Yunnan. Farming culture could have been introduced to Yunnan from other regions for the reasons not necessarily related to resource stress. Alternatively, intensification may have been part of the

subsistence shift process in western Yunnan but occurred much later in the Holocene. Whether the Tangzigou pattern was a local phenomenon from a limited time period or a general trend in broader Yunnan Province during the Early Holocene is still a subject to further testing.

Although the lack of zooarchaeological and taphonomic studies from western China and Southeast Asia in this important time period frustrates comparisons, there are several Late Pleistocene-Early Holocene sites around Tangzigou with the potential to provide more information on subsistence pattern. Exploration and test excavations at Wanrengang, Laohudong, and Huoxinshan in Baoshan Prefecture have yielded thousands of mammal bone fragments and stone tools (Jablonski et al., 2003). Hopefully we will see more quantitative analyses of the archaeofauna in the near future that will allow diachronic and inter-site comparisons. Only then we will understand the true meaning of the subsistence pattern from Tangzigou.

5-3. Future directions

The Tangzigou assemblage gave me an opportunity to conduct one of the first detailed quantitative analyses of the archaeofauna from China. This was feasible because of the careful excavation (including thorough sieving) and curating of the animal bones by the 2003 excavation group led by Nina Jablonski. It was an exceptional decision to retrieve and store all of the animal remains regardless of their identifiablity, especially in southwest China where such tradition is not commonly practiced. The detailed conclusions I have been able to reach about the hunting and processing practices evidenced at Tangzigou are a direct result

of this decision to retain and document all bones from the site. As I have shown in this study, we need more assemblages from this region to conduct inter-site and diachronic comparative analyses to reconstruct the process of dietary shift in post-Pleistocene China. This will be possible if the faunal assemblages from archaeological sites are excavated and stored in a similar way with the Tangzigou materials.

In hindsight, it would have been informative to document the spatial distribution of the animal bones more precisely during the excavation. That would have provided useful information on the pre- and post-depositional process of the faunal assemblage. In the future excavations, it is recommended to use a GIS piece-plotting method to document the spatial distribution of the bones and artifacts in the ground.

I suggest three major avenues for future research that are directly related to the Tangzigou assemblage. First, the study of micromammals and invertebrate remains from Tangzigou will help to clarify the environmental settings at Tangzigou. Because micromammals and invertebrates are very sensitive to habitat, their study should reveal more about the immediate surroundings of the Tangzigou site.

Second is the micro-wear analysis of the possible bone tools including antlers. The "antler tools" from Tangzigou that are on display in the Baoshan museum were classified as tools because of their beveled tips, polished tips and transverse fractures. This study (Chapter 4) has shown that such modifications are also caused by normal deer behavior. People could have used the naturally-modified antlers in other activities, such as leather processing and

weaving. The natural vs. human-made modifications are likely to be distinguishable under high powered microscope and SEM. This future study will establish a crucial comparative dataset to evaluate the nature of the purported antler tools from archaeological sites.

Third is the micro-wear analysis of the possible cut marks on the bones. The low number of cut marks might be due to the usage of bamboo tools in the absence of sharp stone tools from the region. Previous research has documented the difference between the cut marks produced with bamboo and stone tools (West and Louys, 2007). Casts for the possible cut marks from Tangzigou have been made and is currently being studied by me using SEM. This future study will establish an important comparative dataset to evaluate the long-standing "bamboo tool hypothesis" in East and Southeast Asia.

5-4. Conclusion

The nature of the subsistence transition from hunting and gathering to farming (domestication of plants and animals) is one of the most intensively debated topics in anthropology. Archaeological research conducted over the past several decades has shown tremendous regional variation in the timing and sequence of this subsistence shift. Because human subsistence patterns are the result of the interaction between humans and the surrounding environment, variation in the local environment can lead to different subsistence strategies. Southwestern China, especially Yunnan Province, warrants further study because its unique topography and climate have contributed to the evolution of a rich endemic local flora and fauna. The 9000-year-old Tangzigou faunal assemblage from Yunnan provided a

test case to examine whether southwest China underwent a similar subsistence transition found in other regions.

Evidence of resource intensification is commonly found in many archaeological assemblages from the Near East and Europe immediately before the onset of domestication during the Pleistocene-Holocene transition. However, zooarchaeological and taphonomic analysis of the Early Holocene Tangzigou faunal assemblage found no such evidence. While the long bones with high yield of meat and marrow were not processed intensively, the low-utility foot bones were heavily broken. This observation, along with the results from the experiments conducted in this study, suggests that the Tangzigou people were not under resource stress, which is indicative of intensification. There are a couple of hypotheses to explain the patterning in the Tangzigou assemblage. First, resource intensification may not have been part of the subsistence shift in Yunnan. Second, intensification may have been part of the subsistence shift in Yunnan but occurred much later than the Tangzigou period. These hypotheses can be tested with more quantitative analyses of archaeofaunal assemblages from the region that will facilitate diachronic and inter-site comparisons. Only then, can an accurate portrait of the human subsistence strategies from Tangzigou emerge. This study was a step toward fulfilling that goal.

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M.A.   Anthropology, Stanford University, 2005
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Selected Publications (peer-reviewed only)
2010   **Jin, J.**, Shipman, P., Documenting natural wear on antlers: A first step in identifying use-wear on purported antler tools. *Quaternary International* 211, 91-102.

2010   Norton, C.J., **Jin, J.**, Hominin morphological and behavioral variation in eastern Asia and Australasia: Current perspectives. *Quaternary International* 211, 1-3.

2009   Norton, C.J., **Jin, J.**, The evolution of modern humans in East Asia: Behavioral perspectives. *Evolutionary Anthropology* 18, 247-260.

Single-authored Book
2008   *Louis Leakey and Jane Goodall*. Gimyoungsa, Korea (Biography in Korean. Best Book in Science Award 2009 by the Korean Ministry of Culture, Sports, and Tourism. Selected book by the Korean High School Teachers Association)

Selected Grants
2009-2010   Henry Luce Foundation/American Council of Learned Societies Dissertation Fellowship in East and Southeast Asian Archaeology and Early History ($28,000)

2009   College of the Liberal Arts Dissertation Support Competition, Penn State University ($2000)

2009   Hill Fellowship, Department of Anthropology, Penn State Univ. ($1843)

2008-2009   University Graduate Fellowship, Penn State University (Tuition and stipend)

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