Title: New Insights into the Origins of Oracle Bone Divination: Ancient DNA from Late Neolithic Chinese Bovines

Author Names: Katherine Brunson¹, Xin Zhao², Nu He², Xiangming Dai³, Antonia Rodrigues⁴, and Dongya Yang⁴

Author Affiliations:

¹Joukowsky Institute for Archaeology and the Ancient World, Brown University
60 George Street
Providence RI 02906, USA

²Institute of Archaeology, Chinese Academy of Social Sciences, Beijing
27 Wangfujing Street, Beijing, 100710. P.R. China.

³National Museum of China, Beijing
16 East Chang'an Avenue, Beijing, 100006. P.R. China.

⁴Department of Archaeology, Simon Fraser University
8888 University Drive
Burnaby, BC V5A 1S6, Canada

Corresponding Author and Present Address:

Katherine Brunson
Joukowsky Institute for Archaeology and the Ancient World
Brown University
60 George Street Box 1837
Providence, RI 02912
619-787-8646; katherine_brunson@brown.edu

Abstract:

Domestic taurine cattle (*Bos taurus*) were introduced to China from Central Asia between 3600-2000 cal BCE. Most of the earliest domestic cattle remains in China come from sacrificial or ritual contexts, especially in the form of oracle bones used in divination rituals. These oracle bones became closely tied to royal authority and are the source of the earliest written inscriptions in ancient China. In this article, we use ancient DNA to identify uninscribed bovine oracle bones from the Longshan period archaeological sites of Taosi and Zhoujiazhuang (late third millennium BCE). We found that in addition to making oracle bones out of domestic cattle scapulae, people also used aurochs (wild cattle: *Bos primigenius*) scapulae for oracle bone divination. Wild water buffalo (*Bubalus mephistopheles*) were also exploited at Zhoujiazhuang, but we did not identify water buffalo oracle bones in our analysis. We propose some morphological criteria that may be useful for distinguishing between these bovine species, but conclude that it is not always possible to identify bovine scapulae based on morphology alone. Our results indicate that wild and domestic bovines were sometimes present at the same sites and their bones were used in similar ways to make oracle bones. This raises the possibility that these species interbred and that people in ancient China may have experimented with managing indigenous Chinese wild bovines.

Keywords: Oracle bones; Longshan; ancient DNA; zooarchaeology; Chinese archaeology

1. Introduction:

Zooarchaeological evidence indicates that domestic taurine cattle (*Bos taurus*) were introduced to China from West Asia between 3600-2000 years before the common era (BCE) (Flad et al., 2007; Lu, 2010). The adoption of cattle herding in central China provided new opportunities for animal management, which had previously focused on raising domestic pigs and dogs (Yuan, 2008; Luo, 2012). Cattle herding also provided a new animal for use in ritual activities, and most of the earliest evidence for domestic cattle in China come from sacrificial or ritual contexts (Lu, 2010). By the Shang Dynasty (ca. 1600-1046 BCE), cattle had replaced pigs as the most important sacrificial animals at Chinese archaeological sites (Yuan and Flad, 2005).

One of the main ritual uses for cattle in ancient China was in oracle bone divination. Animal bones burned during pyro-osteomantic rituals—also known as oracle bones—are a common type of bone artifact found in both domestic and royal ritual contexts at Chinese Neolithic and Bronze Age archaeological sites. Based on inscribed oracle bones from the Shang Dynasty, we know that diviners would ask questions to gods and ancestors regarding a variety of topics including illness, birth, agriculture, warfare, and tribute (Keightley, 2000). They would then use a hot poker to burn thin, flat bones such as ungulate scapulae or turtle plastrons and interpret the cracks that formed (Keightley, 1978; Keightley, 1999). Although people used bones from many different types of animals for divination, cattle oracle bones increased in frequency through time (Flad, 2008). During the Late Shang Dynasty at Anyang (ca. 1250-1046 BCE), most oracle bones were made from cattle scapulae, including many oracle bones used in royal divination rituals and inscribed with the earliest surviving writing in ancient China (Li, 1977; Keightley, 1978; Chang, 1980; Keightley, 1999; Flad, 2008).

Both during the Shang and in preceding periods, cattle and turtle oracle bones were often pre-treated by thinning the bone and drilling or carving hollows to direct the formation of cracks during burning (Keightley, 1978; Flad, 2008; Pak, 2011). Oracle bones made from other taxa generally were not pre-treated. This suggests that special care and attention was given to the preparation of cattle oracle bones because domestic cattle were an important animal in ancient Chinese religion and ideology. The domestic nature of cattle oracle bones has been central to arguments about Shang Dynasty religion and the Shang world view. Some scholars believe that the Shang divided the chaotic world of the wild from the ordered world of the domestic, emphasizing the ability of the Shang kings to “domesticate” and bring order to the spiritual and material worlds through rituals such as divination (Chang, 1983; Keightley, 2000; Fiskesjö, 2001; Campbell, 2007; Campbell, 2014).

Cattle were the main animal used in Shang Dynasty oracle bone divination, and archaeologists have assumed that all bovine oracle bones from earlier periods were also made from domestic cattle bones (Flad, 2008). However, native aurochs (*Bos primigenius*) and water buffalo (*Bubalus mephistopheles*) were also present in North China at the time (Liu et al., 2006; Lu, 2010). These wild bovines are now extinct, though it is unclear exactly when they disappeared from the Chinese landscape. The bones of cattle, aurochs, and water buffalo are morphologically similar. It is possible that wild bovines were used in divination, but that these cases remain unrecognized in the zooarchaeological record. If people in ancient China used wild bovine scapulae to make oracle bones and if these artifacts were prepared with the same care as domestic cattle oracle bones, our understanding of the role of cattle in the development of divination rituals would need to be re-evaluated.

Here we report the use of ancient DNA to identify uninscribed bovine oracle bones from the Longshan period sites of Taosi and Zhoujiazhuang in southern Shanxi Province. These sites contain some of the earliest evidence for extensive domestic cattle exploitation in China, including some of the earliest pre-treated bovine oracle bones (Brunson et al., 2015). Mitochondrial DNA extracted from eight oracle bone specimens and six non-oracle bone specimens indicates that *Bos taurus*, *Bos primigenius*, and *Bubalus mephistopheles* were all present in this region during the Longshan period, and that both domestic *Bos taurus* and *Bos primigenius* bones were used as raw materials to make oracle bones. We discuss potential morphological criteria for distinguishing between the scapulae of *Bos taurus*, *Bos primigenius*, and *Bubalus mephistopheles*. Our results reveal that wild aurochs and domestic cattle remains were sometimes present at the same sites and their bones were used in similar ways. This raises the possibilities that these species could have interbred and that people also experimented with managing indigenous wild bovines. Previously identified oracle bones and zooarchaeological collections need to be carefully re-examined to determine if aurochs remains are also present at other Chinese sites.

2. Archaeological context:

The Longshan period (late third millennium BCE) is a cultural horizon in central northern China that is characterized by proto-urbanism, increasing social complexity, and increasing long-distance interactions between regional cultural variants (Chang, 1986; Liu, 2004; Shelach-Lavi, 2015). Although a few domestic cattle remains have been identified at pre-Longshan era sites from ca. 3600 cal BCE onward (Zhao, 1995; Zhou, 1999; Yu et al., 2011), cattle bones are not found in large numbers until about 2000 BCE (Lu, 2010), making the Longshan period important for understanding the increasing importance of domestic cattle in China.

The Longshan sites of Taosi (ca. 2300-1900 cal BCE) and Zhoujiazhuang (ca. 2300-1750 cal BCE) in the middle Yellow River Valley provide some of the earliest evidence for extensive cattle herding in China (Fig. 1). Cattle make up between about eight and nine percent of the faunal assemblages at both sites (Brunson et al., 2015). Taosi is located in the Linfen basin (N 35°52'55.90", E 111°29'54.89") in southern Shanxi Province. It was a large, urban political and economic center with a city wall, elite palace structures, socially stratified burials, specialized craft production zones, and ritual buildings including what may have been a solar observatory (He, 2013). Zhoujiazhuang, located about 40km south of Taosi in the Yuncheng basin (N 35°29'10.59", E 111°28'12.98"), was another large site that contained residential areas, a cemetery, and was surrounded by a moat. Zhoujiazhuang has material culture that is similar to that at Taosi, although no palaces, elite burials, dedicated craft production zones, or dedicated ritual structures have yet been found at Zhoujiazhuang.

The oracle bones analyzed in this study were all broken pieces found in midden pits within residential areas of the sites. As was the case at most Late Neolithic sites, oracle bone use at Taosi and Zhoujiazhuang was widespread and still fairly *ad hoc* compared to later periods, when it became closely associated with elite ritual practice (Flad, 2008). Almost all of the bovine oracle bones were modified prior to burning by removing the spine and part of the lateral side of the scapula to thin the bone. In some cases, circular hollows were also carved into the bone, with heat subsequently applied inside of the hollows. The Taosi and Zhoujiazhuang examples show that this method of preparing and burning oracle bones—which was dominant at the Shang

capital at Anyang seven hundred years later—was already starting to be practiced during the Longshan period.

We analyzed four bone specimens from Taosi and ten bone specimens from Zhoujiazhuang (Fig. 2, Table S1). Eight of the specimens are scapulae that had part of the lateral blade removed and/or have circular burn marks visible on the surface. These modifications indicate that they were used as oracle bones. We also analyzed two unworked scapulae that do not have evidence of having been used as oracle bones. We included three unworked calcanei (two identified as *Bos* sp. and one identified as *Bubalus mephistopheles* based on morphology), and one unworked astragalus (identified as *Bos* sp. based on morphology) in our analysis to test whether the morphological identifications could be confirmed through ancient DNA analysis.

Fig. 1. Map of Taosi and Zhoujiazhuang showing some of the analyzed oracle bones. Arrows point to locations of burn marks.

ID	BOC4 ZJZ Scapula (L)	BOC5 ZJZ Scapula (L)	BOC9 ZJZ Scapula (L)**	BOC10 ZJZ Scapula (L)**	BOC11 ZJZ Scapula (L)*

Measurements	GLP=71mm; LG=56mm; BG=45mm; SLC=56mm	GLP=79mm; LG=72mm; BG=55mm; SLC=56mm	GLP=98mm; LG=81mm; BG=72mm; SLC=78mm	GLP=81mm; LG=66mm; BG=57mm; SLC= N/A	GLP=77mm; LG=68mm; BG=60mm; SLC=59mm
Observations	Small supraglenoid tubercle.	Small supraglenoid tubercle.	Large. Round glenoid cavity. Bulbous supraglenoid tubercle.	Round glenoid cavity. Bulbous supraglenoid tubercle.	Round glenoid cavity. Small supraglenoid tubercle.
ID	BOC12 ZJZ Scapula (L)*	BOC13 ZJZ Scapula (R)**	BOC15 TS Scapula (L)**	BOC16 TS Scapula (R)**	BOC17 TS Scapula (R)**

Measurements	N/A	GLP=87mm; LG=69mm; BG=61mm; SLC=N/A	GLP=82mm; LG=74mm; BG=64mm; SLC=N/A	N/A	N/A
Observations	Small supraglenoid tubercle.	Round glenoid cavity. Bulbous supraglenoid tubercle.	Bulbous supraglenoid tubercle.		
ID	BOC6 ZJZ Calcaneus (R)	BOC7 ZJZ Calcaneus (R)	BOC8 ZJZ Calcaneus (L)	BOC14 TS Astragalus (R)	Bubalus Modern Scapula (L)

Measurements	LLP=77; LAF=43	N/A	LLP=47; LAF=25	GLI=71; GLm=64; Bd=46; Dm=42; Di=40	GLP=91mm; LG=67mm; BG=57mm; SLC=70mm
Observations	Morphologically similar to Bubalus.		Morphologically similar to Bos taurus.	Morphologically similar to Bos taurus.	Cranial part of glenoid cavity protrudes distally.

Fig. 2. Specimens from Zhoujiazhuang (ZJZ) and Taosi (TS) included in the analysis. Oracle bones are indicated with a * and pre-treated oracle bones are indicated with a **. Calcaneus measurements include the length of the lateral process (LLP) and length of the articular facet for the *os maleolar* on the lateral process (LAF). Other measurements follow Dreisch (1976, Driesch, 1976). Blue indicates *Bos taurus* specimens, red indicates *Bos primigenius* specimens, and green indicates *Bubalus* specimens including a modern scapula from the zooarchaeological laboratory at IA CASS, Beijing.

3. Materials and methods:

3.1 DNA Extraction:

We analyzed eight bovine oracle bone scapulae, as well as six non-oracle bones (Supplemental Table S1). These include two unmodified scapulae, three calcanei, and one astragalus that we were able to identify to species with confidence based on morphology. Each bone was measured following Driesch (1976) using digital calipers. Morphological observations were made prior to removing 1-2g of bone sample for DNA analysis with a saw. DNA extraction and amplification were performed in the dedicated Ancient DNA Laboratory at the Institute of Archaeology, Chinese Academy of Social Sciences (IA CASS) in Beijing following a modified silica-spin column method (Yang et al., 1998).

Samples were decontaminated by submerging them in >10% hypochlorite for 7 minutes, rinsing with distilled water, and irradiating under UV radiation (UVP Crosslinker CL-1000, 254 nm, samples placed 8cm below radiation source) for 30-45 minutes on each side. This step should destroy DNA on the bone surface and in bone pores, leaving pure endogenous DNA enclosed in hydroxyapatite crystals (Salamon et al., 2005). The decontaminated samples were then ground into powder using a liquid nitrogen grinding mill and incubated overnight at 50 °C in lysis buffer (0.5 M EDTA pH 8.0, 0.5% SDS, and 0.5 mg/mL proteinase K). The solutions were centrifuged and 3mL of supernatant was transferred to Amicon Ultra-4 10K centrifugal filters (Millipore, Billerica, MA). The extracts were centrifuged until less than 100 µL of liquid remained and then purified using a Qiagen QIAquick nucleotide removal kit following the manufacturer's protocols (QIAGEN, Hilden, Germany).

We selected previously published PCR primers that target mitochondrial D-loop control regions for cattle (L16022/H16178 and L16137/H16315 (Troy et al., 2001; Cai et al., 2014)) and water buffalo (F213/R381 (Yang et al., 2008)). We also used one additional cattle primer L16159/H16334 and a universal mammal primer L1269/H1346 to test for preservation and contamination. We used a 30µL PCR volume containing 50mM KCl, 10mM Tris-HCl (pH 8), 2.5mM MgCl₂, 0.2mM dNTP, 1.0 mg/mL pig gelatin, 0.3 µM of each primer, 3.0 µL DNA, and 1.5-3.0 U AmpliTaq Gold (Applied Biosystems). We ran the PCR for 60 cycles (95 °C for 30 seconds (denaturing), 52 °C for 30 seconds (annealing), and 70 °C for 40 seconds (extension)) with an initial 12 minute denaturing period at 95 °C and a final 7 minute extension period at 72 °C. We visualized 5 µL of PCR product on a 2% agarose gel using SYBR Green staining. PCR results are listed in Table S3. PCR products were directly sequenced at Invitrogen (Thermo Fisher Scientific Inc.) using Applied Biosystems Big Dye method.

3.2 mtDNA Analysis:

Sequencing results were aligned using Clustal X 2.1 (Larkin et al., 2007). Phylogenetic trees were constructed in MEGA6 (Tamura et al., 2013). We used comparative sequences available on GenBank for *Bos taurus* (V00654) (Anderson et al., 1982), *Bos indicus* (EU177870 and EU177868) (Achilli et al., 2008), and European *Bos primigenius* (GU985279) (Edwards et al., 2010). Cattle haplogroups were assigned following previous studies of mutations in the mitochondrial D-loop sequence from V00654 (Anderson et al., 1982; Mannen et al., 1998; Troy et al., 2001; Mannen et al., 2004; Cai et al., 2014). Water buffalo haplogroups were assigned following previous studies of mutations in the D-loop sequence from swamp (NC_006295) and river (AY195595) varieties of *Bubalus bubalis* (Kierstein et al., 2004; Lei et al., 2007; Yang et al., 2008).

3.3 DNA Sequence Authenticity:

Our research followed several criteria for assessing the authenticity of ancient DNA results (Poinar, 2003): extractions and amplifications were conducted in dedicated facilities with separate pre and post PCR workspaces, multiple extractions were taken from each sample, blanks and negative controls were used, and our results were found to be reproducible using separate samples from the same specimens. Although we did not use bovine-derived reagents or materials, reagent contamination has been reported previously (Leonard et al., 2007; Champlot et al., 2010). If all amplifiable DNA was destroyed, this could cause positive non-template controls (NTC). For each extraction, we included two blanks prepared along with the ancient samples using the same protocol (see Table S3 for a list of all samples and PCR amplification results). During amplification, at least one negative control was included that contained the same PCR solution without DNA extracts. Out of 11 PCR amplifications containing a total of 36 blanks or negative controls, there were only three cases of contamination. One run of universal mammal primer L1269/H1346 had one blank with contamination (sequenced as *Homo sapiens*). A separate run with this primer had contamination of the negative control (sequenced as *Homo sapiens*). Finally, a run of cattle primer L16022/H16178 had contamination in one of the blanks (sequenced as *Bos*). Given that there was only one case of blank contamination with cattle DNA, we conclude that the sequences from the archaeological samples are authentic and are not the result of reagent contamination.

4. Results:

4.1 Radiocarbon Dating:

Two oracle bone specimens from different excavation contexts at Zhoujiazhuang were sampled for AMS radiocarbon dating through Beta Analytic Inc. and calibrated using the INTCAL13 database (Reimer et al., 2013, Table S2). The sample from specimen BOC9 dates to 3670 ± 30 BP (2140-1955 cal BCE; 4090-3905 cal BP). The sample from specimen BOC10 dates to 3500 ± 30 BP (1900-1745 cal BCE; 3850-3695 cal BP). These dates are consistent with previous radiocarbon determinations from Zhoujiazhuang dating the site to ca. 2300-1750 cal BCE. Both of the dated specimens were identified as aurochs using ancient DNA, indicating that aurochs were present in the Yellow River Valley region at least until ca. 1900 cal BCE and did not go extinct until sometime after the Longshan period.

4.2 Ancient DNA Analysis:

We successfully extracted DNA from all fourteen samples using primers that target mitochondrial D-loop control regions for cattle and water buffalo. BLAST results and comparisons with previously studied ancient bovine mtDNA sequences indicate that ten specimens (five oracle bones, two unworked scapulae, two calcanei, and one astragalus) are domestic *Bos taurus*. Two haplogroups of *Bos taurus* (T3 and T4) were present at both sites (Table 1). These haplogroups have also been identified at Taosi in previous studies of ancient cattle DNA (Cai et al., 2014).

Three specimens (all carved oracle bones) do not match any known mtDNA haplogroups for *Bos taurus*. These specimens (BOC9, BOC10, and BOC13) have similar insertions and substitutions as the unique haplogroup C that was recently identified in an East Asian *Bos*

mandible dating to over 10000 years ago (Zhang et al., 2013). We believe that BOC9, BOC10, and BOC13 also belong to haplogroup C and should be classified as wild *Bos primigenius* native to this part of East Asia. A phylogenetic tree with all of the *Bos* samples and comparative sequences from GenBank is shown in Fig. 3.

One specimen (an unworked calcaneus, BOC6) belongs to water buffalo haplogroup KJ1 (Table 2), which has been linked to the extinct Chinese species *Bubalus mephistopheles* (Yang et al., 2008). We believe that BOC6 is wild water buffalo, confirming its identification based on morphology and indicating that this bovine species was also represented at Zhoujiazhuang. Therefore, three bovine species were likely present in the region during the late Longshan period. Both domestic *Bos taurus* and wild *Bos primigenius* were used to make oracle bones. Because two of the *Bos primigenius* oracle bones were made from left scapulae (BOC9 and BOC10), at least two aurochs individuals were present at Zhoujiazhuang.

Table 1.
Variable Positions in Archaeological Sequences using Primers L16022, H16178, L16137, and H16315.

ID	16042	16055	16057	16068	16083	16084	16085	16093	16095	16110	16113	16119	16125	16127	16139	16178	16201-16202	16224	16225	16231	16234	16243-16244	16250	16260	16264	Haplogroup	Notes
V00654	T	T	G	T	A	C	T	G	A	C	T	T	A	C	C	G	-	C	C	C	T	-	A	C	G	T3	<i>Bos taurus</i> reference sequence
KF525852	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	.	A	.	.	T	.	.	G	T	A	C	<i>Bos</i> mandible from NW China
BOC4	C	.	.	.	.	.	.	A	.	.	.	.	.	.	.	.	-	T	T	.	.	A	.	.	.	T4	
BOC5	.	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	.	.	.	A	.	.	.	.	T3	
BOC7	.	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	T3	
BOC8	.	C	.	.	.	.	.	.	.	.	.	.	.	.	.	N	N	N	N	N	N	N	N	N	N	T3	PCR fail for L16137 and H16315
BOC9	.	.	A	C	G	T	C	.	.	T	.	C	T	T	.	.	A	.	.	T	.	.	G	T	A	C	
BOC10	.	.	.	C	G	T	C	.	G	.	C	C	T	.	T	.	A	.	.	T	.	.	G	T	A	C	
BOC11	.	C	.	.	.	.	.	.	.	.	.	.	.	.	.	A	-	.	.	.	.	.	.	.	.	T3	
BOC12	.	.	.	.	.	.	.	.	.	.	.	C	.	.	.	.	-	.	.	.	.	.	.	.	.	T3	
BOC13	.	.	.	C	G	T	C	.	G	.	C	C	T	.	T	.	A	.	.	T	.	.	G	T	A	C	
BOC14	.	.	.	.	.	.	.	.	.	.	.	C	.	.	.	.	-	.	.	.	.	.	.	.	.	T3	
BOC15	C	.	.	.	.	.	.	A	.	.	.	C	.	.	.	N	N	N	N	N	N	N	N	N	N	T4	PCR fail for L16137 and H16315
BOC16	.	.	.	.	.	.	.	.	.	.	.	C	.	.	.	.	-	.	.	.	.	.	.	.	.	T3	
BOC17	.	C	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	T3	

Dots indicate identical sequences and dashes indicate a deletion/insertion.

Table 2.
Variable Positions for Water Buffalo Sample BOC6 using Primers F213 and R381.

ID	16058	16066	16067	16073	16074	16081	16084	16088	16095	16101	16102	16120	16122	16123	16127	16140	16142	16146	16147	16159	16159	16163	16168	Haplogroup
NC_006295	A	G	G	C	A	C	G	G	G	T	C	A	T	G	C	G	C	G	C	A	T	C	C	Swamp type
AY195595	G	A	A	T	A	C	G	G	G	A	T	A	C	A	T	A	T	A	T	G	T	T	T	River type
BOC6	A	A	A	T	G	T	A	A	A	A	C	G	C	A	T	A	T	G	C	A	C	T	T	KJ1

Fig. 3. Neighbor-joining phylogenetic tree for archaeological *Bos* samples (labeled “BOC”). Comparative sequences include *Bos taurus* T3 (GenBank: V00654) (Anderson et al., 1982) and T4 (GenBank: DQ124372) haplogroups, European *Bos primigenius* P haplogroup (GenBank: JQ437479.1 and GenBank: GU985279) (Edwards et al., 2010), and *Bos indicus* I haplogroups (GenBank: EU177870 and EU177868) (Achilli et al., 2008). *Bubalus bubalis* (GenBank: NC_006295) is included as an outgroup. All major nodes are labeled with bootstrap values (% of 2000 replicates). Scale bar indicates the number of amino acid substitutions per site.

4.3 Morphological observations:

To examine morphological and metric traits that may be useful for identifying the various bovine taxa, we focused on the distal scapula, which is denser than other parts of the scapula and more likely to survive archaeologically. The largest aurochs scapula (BOC9) falls within the size range of European *Bos primigenius* (Degerbøl and Fredskild, 1970). The two other aurochs scapulae (BOC10 and BOC13) overlap in size with *Bos taurus* (Fig. 4). Additionally, the *Bos taurus* and *Bos primigenius* scapulae are morphologically similar. We observed that the aurochs scapulae all have a more pronounced notch on the lateral side of the glenoid cavity. The supraglenoid tubercle also tends to be more bulbous in the aurochs specimens, but this observation needs to be tested on additional comparative materials. The feature may simply be related to the animal’s size, since the large domestic cattle scapula BOC15 also has a bulbous coracoid process. Our initial observations of modern water buffalo scapulae from collections at the Institute of Archaeology of the Chinese Academy of Social Sciences and at the Henan

Provincial Institute of Archaeology suggest that the cranial lip of the glenoid cavity tends to project distally in *Bubalus* more than it does in *Bos*. This observation still needs to be confirmed for archaeological *Bubalus mephistopheles* scapulae. Future studies using more detailed morphometric methods may help to distinguish between the similar looking bones of these bovine species.

Fig. 4. Plot of scapula measurements for the greatest length of the glenoid process (GLP) and greatest breadth of the glenoid cavity (BG) (Driesch, 1976). *Bos primigenius* scapulae are shown in red and *Bos taurus* scapulae are shown in blue. The green point is a modern *Bubalus bubalis* scapula from the Henan Provincial Institute of Archaeology. Bars indicate ranges for the measurements of European aurochs (red) and domestic cattle (blue) listed in Degerbøl and Fredskild (1970, Degerbøl and Fredskild, 1970): Aurochs GLP: 81-100mm; aurochs BG: 58-77mm; domestic cattle GLP: 61-85mm; domestic cattle BG: 40-63. There is considerable overlap between the largest *Bos taurus* scapulae and the smallest *Bos primigenius* scapulae.

5. Discussion:

Archaeologists and geneticists are in general agreement that there were two independent centers of domestication for cattle. Taurine cattle were first domesticated from wild aurochs in the Near East by ca. 8000 BCE (Loftus et al., 1994; MacHugh et al., 1997; Loftus et al., 1999; Helmer et al., 2005; Bradley and Magee, 2006; Hongo et al., 2009). Zebu cattle (*Bos indicus*) were domesticated in a separate domestication event in South Asia by ca. 6000 BCE (Grigson, 1985; Loftus et al., 1994; Meadow, 1996; Loftus et al., 1999; Meadow and Patel, 2003; Chen et al., 2009). In China, all archaeological samples of domestic cattle studied genetically so far, including those presented here, belong to *Bos taurus* mtDNA haplogroups (Cai et al., 2014). The earliest evidence for zebu cattle in the archaeological record comes from depictions of humped cattle on bronzes dating to 475-221 BCE (Zhang, 1998; Chen, 1999). It is still unclear when *Bos indicus* entered China, so our discussion focuses on *Bos taurus* and its relationship with *Bos primigenius* in East Asia.

Taurine cattle populations worldwide belong to several main mtDNA haplogroups that originated in the Near East (Troy et al., 2001). Haplogroups T, T2, and T3 are most common in the Near East and Europe, haplogroup T1 is found almost exclusively in Africa, and haplogroup T4 is found only in East Asia (Mannen et al., 1998; Troy et al., 2001; Mannen et al., 2004; Bradley and Magee, 2006; Achilli et al., 2008; Achilli et al., 2009; Magee et al., 2014). Another *Bos taurus* haplogroup, T5, has also been identified in modern Italian cattle (Achilli et al., 2008; Achilli et al., 2009). Because the T4 haplogroup is only found in East Asian cattle, some scholars have argued that there was another independent domestication event in East Asia (Mannen et al., 1998; Mannen et al., 2004; Lai et al., 2006); however, more recent research shows that the T4 haplogroup is a derived clade within the T3 haplogroup (Achilli et al., 2008; Achilli et al., 2009).

Other rare *Bos* mtDNA haplogroups provide evidence for interbreeding between domestic cattle and wild aurochs populations. Ancient European aurochs belong to haplogroup P, although a single aurochs specimen from Neolithic Germany has also been identified as haplogroup E (Edwards et al., 2007; Edwards et al., 2010). When cattle were introduced to Europe, they interbred with native aurochs matriline, resulting in rare haplogroups Q and R (Achilli et al., 2009). Male introgression in Europe has also been argued based on Y-chromosome studies (Götherström et al., 2005), but these conclusions are subject to debate (Bollongino et al., 2008). Recent whole-genome studies of European aurochs provide additional evidence that domestic and wild populations may have occasionally interbred (Park et al., 2015).

The possibility for interbreeding between native wild bovine populations and introduced domesticates has not been explored in East Asia. Previous ancient DNA research has shown that the T2, T3, and T4 haplogroups were all present in China by ca. 2000 BCE (Cai et al., 2014). There is currently no archaeological or genetic evidence indicating that cattle were domesticated indigenously from Chinese wild aurochs. Instead, zooarchaeological evidence that domestic cattle bones first appear in northwest China along proto-silk Road trade routes (Flad et al., 2007; Lu, 2010), combined with genetic evidence that all ancient and modern Chinese *Bos taurus* haplogroups originated in or were derived from Near Eastern haplogroups (Lai et al., 2006; Achilli et al., 2008; Achilli et al., 2009; Cai et al., 2014) suggests that Chinese domestic cattle likely originated in the Near East. However, very little is known about East Asian aurochs genetics. In addition to the three *Bos primigenius* oracle bone specimens presented in this paper, only one other ancient DNA study of East Asian wild aurochs has been published (Zhang et al., 2013). The authors of that study sequenced the complete mitogenome of a *Bos* mandible found in northeastern China with 16.7-fold coverage. They argue that this specimen was a managed individual, but the zooarchaeological and morphological evidence for such a claim is not well supported (Lu, 2014). Nevertheless, their study is noteworthy because they identified a new *Bos* haplogroup C that is distinct from all other known modern *Bos taurus* haplogroups.

We have identified additional *Bos* specimens belonging to haplogroup C. These specimens date to significantly later in the Holocene and represent the first identified cases associated with solid archaeological contexts. Our results also demonstrate that East Asian cattle of haplogroup C were present alongside cattle of haplogroups T3 and T4. Not only were native and non-native cattle populations living in the same geographic region, but people were exploiting both of these populations, which provided opportunities for interbreeding. This raises several interesting possibilities: 1) that domestic cattle and native East Asian wild aurochs interbred sporadically without intentional human direction; 2) that people in ancient China intentionally bred wild and domestic stocks, perhaps as a means of increasing genetic diversity to improve herd health; 3) that people intentionally deterred interbreeding between wild and

domestic populations; and 4) that people experimented with managing wild bovine populations in ways that did not result in full domestication. All previous research on ancient Chinese cattle genetics, including our current study, has focused on mtDNA. Nuclear DNA data are still needed to determine whether East Asian wild aurochs and domestic cattle populations interbred at sites such as Zhoujiazhuang.

Our results also demonstrate that wild water buffalo were present alongside domestic and wild cattle populations. Although we did not identify any water buffalo oracle bones, we did identify one calcaneus from Zhoujiazhuang as from wild water buffalo. Mitochondrial DNA research on modern animals indicates that swamp water buffalo may have been domesticated in southwest China or southeast Asia (Yue et al., 2013). The earliest zooarchaeological evidence for domestic water buffalo in China dates to after the first century CE, with all earlier water buffalo specimens likely belonging to the extinct wild *Bubalus mephistopheles* (Liu et al., 2006). Ancient mtDNA evidence indicates that *Bubalus mephistopheles* from northern Chinese sites dating to ca. 2000 BCE did not contribute genetically to modern domestic Chinese water buffalo (Yang et al., 2008). As with cattle, nuclear DNA studies are needed to determine whether there was interbreeding between domestic water buffalo populations introduced into north China and the now-extinct wild *Bubalus mephistopheles*.

The Taosi and Zhoujiazhuang cases presented here also show that the practice of pre-treating oracle bones was already taking place to some degree in the Yellow River Valley by ca. 2000 cal BCE and that it was not unique to domestic cattle scapulae. Most of the oracle bones that we analyzed were pre-treated by flattening the lateral side of the scapula and carving hollows to direct the formation of cracks. Similar pre-treatment methods for bovine scapulae eventually became highly standardized later in the Bronze Age, which is said to be a sign of increasing state control over oracle bone divination (Keightley, 1978; Keightley, 2000; Flad, 2008). The use of aurochs bones for divination at Zhoujiazhuang may indicate that both wild and domestic bovines were seen as equally important ritual animals at that time or that aurochs could be used as a substitute for domestic cattle. Hybrid animals may have also been used. If these were not F1 hybrids, their phenotype could look similar to domestic cattle. The possibility for hybrid animal exploitation in China needs to be examined further, but the presence of pre-treated C haplogroup oracle bones at Zhoujiazhuang suggests that the specialized treatment of oracle bones at later Bronze Age sites may not have been reserved for domestic cattle.

It remains unclear what cultural preferences influenced the selection of bovine bones for oracle bone divination or for artifact production in ancient China. Oracle bone divination became more common in the late second millennium BCE after the widespread adoption of cattle herding in the central plains region (Flad et al., 2007; Flad, 2008). Bovines have the largest, flattest scapulae of all common mammalian taxa present in ancient China. Before the arrival of domestic cattle, people would have only had occasional access to scapulae from hunted wild aurochs and water buffalo. It is likely that the adoption of cattle herding at sites like Taosi and Zhoujiazhuang may have increased the availability of desirable bone materials for divination and promoted the spread of oracle bone divination rituals during the Longshan and subsequent periods.

In addition to being used to make oracle bones, bovine bones were an important raw material for making utilitarian artifacts at Taosi and Zhoujiazhuang (Brunson et al., 2015). A few hundred years later during the Shang Dynasty, cattle bones became the main raw material for bone artifact production at massive bone workshops (Ma, 2010; Campbell et al., 2011; ZSKY et al. Zhongguo, 2015). The degree to which aurochs or water buffalo were used in bone artifact

production in these contexts is unknown^{*}. Earlier in the Neolithic, worked water buffalo scapulae have been identified as agricultural and other utilitarian tools at sites in the Yangzi River Valley (Xie et al., 2016). To our knowledge, no other water buffalo utilitarian artifacts or oracle bones have been identified elsewhere in China. Additional research is needed to know whether people intentionally avoided using water buffalo or if their bones have simply not yet been identified. The absence of water buffalo in Shang period oracle bone collections is particularly striking in light of the frequent depiction of water buffalo on ritual bronzes, which would suggest that these animals had important symbolic and ritual meanings. Questions about the intentional selection for or against using certain types of bovines in utilitarian artifact production and divination rituals highlights the importance of accurately identifying the types of animals used to make oracle bones.

We propose a few preliminary criteria that may be useful for identifying bovine scapulae at other Chinese sites: 1) the aurochs scapulae we analyzed all have a deep notch in the lateral side of the glenoid cavity that is generally more pronounced than in domestic cattle; 2) the aurochs scapulae tend to have a larger and more bulbous supraglenoid tubercle compared to domestic cattle; 3) the cranial portion of the glenoid cavity in water buffalo scapulae protrudes distally more than in either species of *Bos*. We are in the process of testing these criteria using additional comparative skeletal collections. It is important to note that key morphological traits may not always be visible on fragmentary or broken archaeological scapulae. Oracle bones may be even harder to identify to species because diagnostic sections of the scapula are frequently removed. For example, many Shang Dynasty oracle bones from Anyang have the entire lateral side of the glenoid cavity removed and a notch cut from the supraglenoid tubercle (Keightley, 1978; Pak, 2011). Additionally, because there can be considerable size overlap between wild and domestic bovines, size alone cannot be used to identify or exclude the presence of wild bovines. For many cases it may not be possible to identify specimens confidently to genus or species without the use of biomolecular methods. These considerations pose challenges to research on the types of bovines used to make oracle bones and underscore the possibility that wild bovines remain unrecognized in existing collections of oracle bones.

It is also possible that wild bovine bones remain unrecognized in archaeological faunal collections in China more generally. This is especially likely for aurochs bones, which are rarely identified for periods after domestic cattle were introduced to China. Our current analysis indicates that these wild species persisted in China long after the introduction of domestic cattle. Although there is currently no evidence that East Asian aurochs populations interbred with domestic cattle or that people in ancient China managed wild bovines, very few sites or specimens have been analyzed in depth. If aurochs and water buffalo were present at the same sites alongside domestic cattle and their bones were used in similar ways, as was the case at Zhoujiazhuang, we need to question the prevailing assumption that wild aurochs disappeared as soon as domestic cattle arrived in northern China and that water buffalo bones found archaeologically always represent wild, unmanaged animals.

^{*} Water buffalo make up less than 1% of identified large bovine bones identified at Tiesanlu in Anyang (Roderick Campbell and Zhipeng Li, personal communication), but only certain skeletal elements can be used to differentiate water buffalo from cattle. To our knowledge, aurochs have not yet been identified in other worked bone artifact collections from China.

6. Conclusion:

We have identified the first known cases of oracle bones made from aurochs (*Bos primigenius*) scapulae. These specimens are directly dated to ca. 1900 cal BCE, indicating that wild aurochs were still extant in northern China during the terminal Late Neolithic and Early Bronze Age. Our findings indicate that people living in the Yellow River Valley were exploiting both wild and domestic bovines, thus providing evidence that opportunities existed for interbreeding and experimentation with management of wild populations. Our results also suggest that it may not always be possible to identify wild bovine worked bone artifacts based on morphology alone. Previously identified oracle bones and zooarchaeological collections should be carefully re-examined to determine if aurochs were also present at other Chinese sites. Although there is currently no genetic evidence that domestic cattle and wild aurochs populations interbred, ancient DNA research on Chinese cattle is only just beginning. The application of additional zooarchaeological, genetic, and isotopic research will be critical for understanding the conditions under which cattle herding was adopted in China, the relationship between domestic cattle and East Asian wild aurochs, and the role of cattle, aurochs, and water buffalo in ancient Chinese ritual practice.

Acknowledgements:

We would like to thank the researchers and students at IA CASS, especially Lu Peng, Li Zhipeng, Yuan Jing, and the other members of the zooarchaeology lab for their assistance with the research and permission to use the photo of a modern water buffalo scapula. We also thank the Henan Provincial Institute of Archaeology, the UCLA Department of Anthropology, the Cotsen Institute of Archaeology, the Harvard Fairbank Center for Chinese Studies, Jeffrey Brantingham, Lothar von Falkenhausen, Rowan Flad, Richard Meadow, Li Min, Gregson Schachner, and Thomas Wake. Brunson was supported by the US National Science Foundation GRFP (DGE-1144087) and DIG (BCS-1249600), by the UCLA Cotsen Institute Friends of Archaeology, and by the Harvard Fairbank Center for Chinese Studies. Zhao was supported by the Chinese National Science Fund Project “Molecular Research on Pre-Qin Period Domestic Cattle in the Central Plains Region” (15CKG017) and Research on the Origins of Chinese Civilization and Related Technologies for Cultural Relics Preservation: Resources, Technologies, and Industry during the Formation of Chinese Civilization (2013-2015). Yang and Rodrigues were supported by research grants from SSHRC Canada.

References:

- Achilli, A., Bonfiglio, S., Olivieri, A., Malusà, A., Pala, M., Kashani, B.H., Perego, U.A., Ajmone-Marsan, P., Liotta, L., Semino, O., Bandelt, H.-J., Ferretti, L., Torroni, A., 2009. The multifaceted origin of taurine cattle reflected by the mitochondrial genome (the origin of taurine cattle). *PLoS ONE* 4, e5753. doi: 10.1371/journal.pone.0005753
- Achilli, A., Olivieri, A., Pellecchia, M., Ubaldi, C., Colli, L., Al-Zahery, N., Accetturo, M., Pala, M., Kashani, B.H., Perego, U.A., Battaglia, V., Fornarino, S., Kalamati, J., Houshmand, M., Negrini, R., Semino, O., Richards, M., Macaulay, V., Ferretti, L., Bandelt, H.-J., Ajmone-Marsan, P., Torroni, A.,

2008. Mitochondrial genomes of extinct aurochs survive in domestic cattle. *Current Biology* 18, R157-R158. doi: 10.1016/j.cub.2008.01.019
- Anderson, S., de Bruijn, M.H.L., Coulson, A.R., Eperon, I.C., Sanger, F., Young, I.G., 1982. Complete sequence of bovine mitochondrial DNA conserved features of the mammalian mitochondrial genome. *Journal of Molecular Biology* 156, 683-717. doi: 10.1016/0022-2836(82)90137-1
- Bollongino, R., Elsner, J., Vigne, J.-D., Burger, J., 2008. Y-snps do not indicate hybridisation between european aurochs and domestic cattle (bovine y-haplotypes). *PLoS ONE* 3, e3418. doi: 10.1371/journal.pone.0003418
- Bradley, D.G., Magee, D.A., 2006. Genetics and the origins of domestic cattle, In: Zeder, M.A., Bradley, D.G., Emshwiller, E., Smith, B.D. (Eds.), *Documenting domestication: New genetic and archaeological paradigms*, University of California Press, Berkeley, CA, pp. 317-328.
- Brunson, K., He, N., Dai, X., 2015. Sheep, cattle, and specialization: New zooarchaeological perspectives on the taosi longshan. *International Journal of Osteoarchaeology*. doi: 10.1002/oa.2436
- Cai, D., Sun, Y., Tang, Z., Hu, S., Li, W., Zhao, X., Xiang, H., Zhou, H., 2014. The origins of chinese domestic cattle as revealed by ancient DNA analysis. *Journal of Archaeological Science* 41, 423-434. doi: 10.1016/j.jas.2013.09.003
- Campbell, R.B., 2007. Blood, flesh and bones: Kinship and violence in the social economy of the Late Shang, Harvard University PhD Dissertation.
- Campbell, R.B., 2014. Animal, human, God: Pathways of Shang animality and divinity, In: Arbuckle, B.S., McCarty, S.A. (Eds.), *Animals and inequality in the ancient world*, University Press of Colorado, Boulder, CO, pp. 251-273.
- Campbell, R.B., Li, Z., He, Y., Jing, Y., 2011. Consumption, exchange and production at the great settlement Shang: Bone-working at Tiesanlu, Anyang. *Antiquity* 85, 1279-1297.
- Champlot, S., Berthelot, C., Pruvost, M., Bennett, E.A., Grange, T., Geigl, E.-M., 2010. An efficient multistrategy DNA decontamination procedure of PCR reagents for hypersensitive PCR applications (DNA decontamination). *PLoS ONE* 5, e13042. doi: 10.1371/journal.pone.0013042
- Chang, K.C., 1980. *Shang civilization*, Yale University Press, New Haven, CT.
- Chang, K.C., 1983. *Art, myth, and ritual: The path to political authority in ancient China*, Harvard University Press, Cambridge, Massachusetts, and London, England.
- Chang, K.C., 1986. *The archaeology of ancient China*. 4th ed., Yale University Press, New Haven, CT.
- Chen, S., Lin, B.-Z., Baig, M., Mitra, B., Lopes, R.J., Santos, A.M., Magee, D.A., Azevedo, M., Tarroso, P., Sasazaki, S., Ostrowski, S., Mahgoub, O., Chaudhuri, T.K., Zhang, Y.-p., Costa, V., Royo, L.J., Goyache, F., Luikart, G., Boivin, N., Fuller, D.Q., Mannen, H., Bradley, D.G., Beja-Pereira, A., 2009. Zebu cattle are an exclusive legacy of the South Asia Neolithic. *Molecular Biology and Evolution* 27, 1-6. doi: 10.1093/molbev/msp213
- Chen, X., 1999. Lingnan diqu niu de kaogu faxin yu yanjiu [Archaeological discoveries and research on cattle in the Lingnan region]. *Xueshu Luntan* 4, 13-18.
- Degerbøl, M., Fredskild, B., 1970. The urus (*Bos primigenius bojanus*) and Neolithic domesticated cattle (*Bos taurus domesticus* linné) in Denmark. With a revision of Bos-remains from the kitchen middens. *Zoological and palynological investigations*, (Munksgaard), København.
- Driesch, A.v.d., 1976. *A guide to the measurement of animal bones from archaeological sites*, Peabody Museum of Archaeology and Ethnology, Harvard University, Cambridge, MA.
- Edwards, C.J., Bollongino, R., Scheu, A., Chamberlain, A., Tresset, A., Vigne, J.-D., Baird, J.F., Larson, G., Ho, S.Y.W., Heupink, T.H., Shapiro, B., Freeman, A.R., Thomas, M.G., Arbogast, R.-M., Arndt, B., Bartosiewicz, L., Benecke, N., Budja, M., Chaix, L., Choyke, A.M., Coqueugniot, E., Döhle, H.-J., Göldner, H., Hartz, S., Helmer, D., Herzig, B., Hongo, H., Mashkour, M., Özdoğan, M., Pucher, E., Roth, G., Schade-Lindig, S., Schmölcke, U., Schulting, R.J., Stephan, E., Uerpmann, H.-P., Vörös, I., Voytek, B., Bradley, D.G., Burger, J., 2007. Mitochondrial DNA analysis shows a Near Eastern Neolithic origin for domestic cattle and no indication of domestication of European aurochs. *Proceedings: Biological Sciences* 274, 1377-1385. doi: 10.1098/rspb.2007.0020

- Edwards, C.J., Magee, D.A., Park, S.D.E., McGettigan, P.A., Lohan, A.J., Murphy, A., Finlay, E.K., Shapiro, B., Chamberlain, A.T., Richards, M.B., Bradley, D.G., Loftus, B.J., MacHugh, D.E., 2010. A complete mitochondrial genome sequence from a Mesolithic wild aurochs (*Bos primigenius*) (an aurochs mtDNA genome). *PLoS ONE* 5, e9255. doi: 10.1371/journal.pone.0009255
- Fiskesjö, M., 2001. Rising from blood-stained fields: Royal hunting and state formation in Shang China. *Bulletin-Museum of Far Eastern Antiquities*, 48-191.
- Flad, R.K., 2008. Divination and power: A multiregional view of the development of oracle bone divination in early China. *Current Anthropology* 49, 403-437. doi: 10.1086/588495
- Flad, R.K., Yuan, J., Li, S., 2007. Zooarcheological evidence for animal domestication in northwest China, In: Madsen, D.B., Chen, F.-H., Gao, X. (Eds.), *Late quaternary climate change and human adaptation in arid China*, Elsevier, Amsterdam; London, pp. 167-204.
- Götherström, A., Anderung, C., Hellborg, L., Elburg, R., Smith, C., Bradley, D.G., Ellegren, H., 2005. Cattle domestication in the Near East was followed by hybridization with aurochs bulls in Europe. *Proceedings. Biological sciences / The Royal Society* 272, 2345-3450. doi: 10.1098/rspb.2005.3243
- Grigson, C., 1985. *Bos indicus* and *Bos namadicus* and the problem of autochthonous domestication in India, In: Misra, V.N., Bellwood, P.S. (Eds.), *Recent advances in Indo-Pacific prehistory*. Oxford and IBH, New Delhi, India, pp. 425-428.
- He, N., 2013. The Longshan period site of Taosi in southern Shanxi Province, In: Underhill, A.P. (Ed.), *A companion to Chinese archaeology*, John Wiley & Sons Inc., Chichester, West Sussex, pp. 255-277.
- Helmer, D., Gourichon, L., Monchot, H., Peters, J., Segui, M.S., 2005. Identifying early domestic cattle from Pre-Pottery Neolithic sites on the middle Euphrates using sexual dimorphism, In: Vigne, J.-D., Peters, J., Helmer, D. (Eds.), *The first steps of animal domestication: New archaeobiological approaches*, Oxbow [Distributed in the U.S. by] D. Brown Bk. Co., Oxford: Oakville, CT, pp. 86-95.
- Hongo, H., Pearson, J., Öksüz, B., Ilgezdi, G., 2009. The process of ungulate domestication at Çayönü, southeastern Turkey: A multidisciplinary approach focusing on *Bos* sp. and *Cervus elaphus*. *Anthropozoologica* 44, 63-78. doi: 10.5252/az2009n1a3
- Keightley, D.N., 1978. *Sources of Shang history: The oracle-bone inscriptions of Bronze Age China*, University of California Press, Berkeley.
- Keightley, D.N., 1999. The Shang: China's first historical dynasty, In: Loewe, M., Shaughnessy, E.L. (Eds.), *The Cambridge history of ancient China: From the origins of civilization to 221 B.C.*, Cambridge University Press, Cambridge, UK, pp. 232-291.
- Keightley, D.N., 2000. *The ancestral landscape: Time, space, and community in Late Shang China (ca. 1200-1045 b.C.)*, University of California, Berkeley, Berkeley.
- Kierstein, G., Vallinoto, M., Silva, A., Schneider, M.P., Iannuzzi, L., Brenig, B., 2004. Analysis of mitochondrial d-loop region casts new light on domestic water buffalo (*Bubalus bubalis*) phylogeny. *Molecular Phylogenetics and Evolution* 30, 308-324. doi: 10.1016/S1055-7903(03)00221-5
- Lai, S.-J., Liu, Y.-P., Liu, Y.-X., Li, X.-W., Yao, Y.-G., 2006. Genetic diversity and origin of Chinese cattle revealed by mtDNA d-loop sequence variation. *Molecular Phylogenetics and Evolution* 38, 146-154. doi: 10.1016/j.ympev.2005.06.013
- Larkin, M.A., Blackshields, G., Brown, N.P., Chenna, R., McGettigan, P.A., McWilliam, H., Valentin, F., Wallace, I.M., Wilm, A., Lopez, R., Thompson, J.D., Gibson, T.J., Higgins, D.G., 2007. Clustal W and Clustal X version 2.0. *Bioinformatics* 23, 2947-2948. doi: 10.1093/bioinformatics/btm404
- Lei, C.Z., Zhang, W., Chen, H., Lu, F., Liu, R.Y., Yang, X.Y., Zhang, H.C., Liu, Z.G., Yao, L.B., Lu, Z.F., Zhao, Z.L., 2007. Independent maternal origin of Chinese swamp buffalo (*Bubalus bubalis*). *Animal Genetics* 38, 97-102. doi: 10.1111/j.1365-2052.2007.01567.x
- Leonard, J.A., Shanks, O., Hofreiter, M., Kreuz, E., Hodges, L., Ream, W., Wayne, R.K., Fleischer, R.C., 2007. Animal DNA in PCR reagents plagues ancient DNA research. *Journal of Archaeological Science* 34, 1361-1366. doi: 10.1016/j.jas.2006.10.023
- Li, J., 1977. *Anyang*, University of Washington Press, Seattle.
- Liu, L., 2004. *The Chinese Neolithic: Trajectories to early states*, Cambridge University Press, Cambridge, UK, New York.

- Liu, L., Yang, D., Chen, X., 2006. Zhongguo jiaoyang shuiniu de qiyuan chutan [On the origin of the *Bubalus bubalis* in China]. *Kaogu Xuebao* 2, 141 - 178.
- Loftus, R.T., Ertugrul, O., Harba, A.H., El - barody, M.A.A., Machugh, D.E., Park, S.D.E., Bradley, D.G., 1999. A microsatellite survey of cattle from a centre of origin: The Near East. *Molecular Ecology* 8, 2015-2022. doi: 10.1046/j.1365-294x.1999.00805.x
- Loftus, R.T., Machugh, D.E., Ngere, L.O., Balain, D.S., Badi, A.M., Bradley, D.G., Cunningham, E.P., 1994. Mitochondrial genetic variation in European, African and Indian cattle populations. *Animal Genetics* 25, 265-271. doi: 10.1111/j.1365-2052.1994.tb00203.x
- Lu, P., Yuan Jing, Li Zhipeng 2014. Zailun Zhongguo jiaoyang huangniu de qiyuan: Shangque 'zhongguo dongbei diqu quanshixinzaqi huangniu de xingtaixue he jiyinxue zhengju' yiwen [Re-exploration the origination of domesticated cattle in China——Discussion on "morphological and genetic evidence for early Holocene cattle management in northeastern China." *Nanfang Wenwu* 3, 48-59.
- Lu, P. 2010. Lun zhongguo jiaoyang huangniu de qiyuan [Discussion of the origins of Chinese domestic cattle], *Dongwu kaogu*, di 1 ji , Wenwu Chubanshe, Beijing, pp. 152-176.
- Luo, Y. 2012. Zhongguo gudai zhu lei xunhua, siyang yu yishixing shiyong [The domestication, feeding, and ritual use of ancient Chinese pigs], *Kexue Chubanshe*, Beijing.
- Ma, X. 2010. Guanyu Zhongguo guqi yanjiu de gi ge wenti [Discussion of a few questions related to Chinese bone artifact research]. *Huaxia Kaogu* 2, 138-142.
- MacHugh, D.E., Shriver, M.D., Loftus, R.T., Cunningham, P., Bradley, D.G., 1997. Microsatellite DNA variation and the evolution, domestication and phylogeography of taurine and zebu cattle (*Bos taurus* and *Bos indicus*). *Genetics* 146, 1071-1086.
- Magee, D.A., Machugh, D.E., Edwards, C.J., 2014. Interrogation of modern and ancient genomes reveals the complex domestic history of cattle. *Animal Frontiers* 4, 7-22. doi: 10.2527/af.2014-0017
- Mannen, H., Kohno, M., Nagata, Y., Tsuji, S., Bradley, D.G., Yeo, J.S., Nyamsamba, D., Zagdsuren, Y., Yokohama, M., Nomura, K., Amano, T., 2004. Independent mitochondrial origin and historical genetic differentiation in north eastern Asian cattle. *Molecular Phylogenetics and Evolution* 32, 539-544. doi: 10.1016/j.ympev.2004.01.010
- Mannen, H., Tsuji, S., Loftus, R.T., Bradley, D.G., 1998. Mitochondrial DNA variation and evolution of Japanese black cattle (*Bos taurus*). *Genetics* 150, 1169-1175.
- Meadow, R.H., 1996. The origins and spread of pastoralism in northwestern South Asia, In: Harris, D.R. (Ed.), *The origins and spread of agriculture and pastoralism in Eurasia*, UCL Press, London, pp. 390-412.
- Meadow, R.H., Patel, A.K., 2003. Prehistoric pastoralism in northwestern South Asia from the Neolithic through the Harappan period, In: Weber, S.A., Belcher, W.R. (Eds.), *Indus ethnobiology: New perspectives from the field*, Lexington Books, Lanham MD, pp. 65-93.
- Pak, C.B. 2011. Xian Qin bufa yanjiu [Research on methods of divination in the pre-Qin period], Shanghai gu ji chu ban she, Shanghai
- Park, S.D.E., Magee, D.A., McGettigan, P.A., Teasdale, M.D., Edwards, C.J., Lohan, A.J., Murphy, A., Braud, M., Donoghue, M.T., Liu, Y., Chamberlain, A.T., Rue-Albrecht, K., Schroeder, S., Spillane, C., Tai, S., Bradley, D.G., Sonstegard, T.S., Loftus, B.J., Machugh, D.E., 2015. Genome sequencing of the extinct Eurasian wild aurochs, *Bos primigenius*, illuminates the phylogeography and evolution of cattle. *Genome Biology* 16, 234. doi: 10.1186/s13059-015-0790-2
- Poinar, H.N., 2003. The top 10 list: Criteria of authenticity for DNA from ancient and forensic samples. *International Congress Series* 1239, 575-579. doi: 10.1016/S0531-5131(02)00624-6
- Reimer, P.J., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Bronk Ramsey, C., Buck, C.E., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hafflidason, H., Hajdas, I., Hatté, C., Heaton, T.J., Hoffmann, D.L., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., Manning, S.W., Niu, M., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Staff, R.A., Turney, C.S.M.,

- Plicht, J.v.d., 2013. Intcal13 and marine13 radiocarbon age calibration curves 0–50,000 years cal BP. *Radiocarbon* 55, 1869-1887. doi: 10.2458/azu_js_rc.55.16947
- Salamon, M., Tuross, N., Arensburg, B., Weiner, S., 2005. Relatively well preserved DNA is present in the crystal aggregates of fossil bones. *PNAS* 102, 13783. doi:
- Shelach-Lavi, G., 2015. *The archaeology of early China: From prehistory to the Han dynasty*, Cambridge University Press, New York, NY.
- Tamura, K., Stecher, G., Peterson, D., Filipski, A., Kumar, S., 2013. Mega6: Molecular Evolutionary Genetics Analysis version 6.0, pp. 2725-2729. doi: 10.1093/molbev/mst197
- Troy, C.S., MacHugh, D.E., Bailey, J.F., Magee, D.A., Loftus, R.T., Cunningham, P., Chamberlain, A.T., Sykes, B.C., Bradley, D.G., 2001. Genetic evidence for Near-Eastern origins of European cattle. *Nature* 410, 1088. doi: 10.1038/35074088
- Xie, L., Lu, X., Sun, G., Huang, W., 2016. Functionality and morphology: Identifying si agricultural tools from among Hemudu scapular implements in eastern China. *Journal of Archaeological Method and Theory*, 1-47. doi: 10.1007/s10816-015-9271-x
- Yang, D., Eng, B., Wayne, J.S., Dudar, J.C., Saunders, S.R., 1998. Improved DNA extraction from ancient bones using silica-based spin columns. *American Journal of Physical Anthropology* 105, 539-543. doi: 10.1002/(SICI)1096-8644(199804)105:4<539::AID-AJPA10>3.0.CO2-1
- Yang, D., Liu, L., Chen, X., Speller, C.F., 2008. Wild or domesticated: DNA analysis of ancient water buffalo remains from north China. *Journal of Archaeological Science* 35, 2778-2785. doi: 10.1016/j.jas.2008.05.010
- Yu, C., Lu, P., Zhao, C. 2011. Gansu sheng Lixian Xishan yizhi chutu dongwu guge jian ding yu yanjiu [Identification and research on animal bones from Xishan, Li county, Gansu Province]. *Nanfang Wenwu* 3, 73-79.
- Yuan, J., 2008. The origins and development of animal domestication in China. *Chinese Archaeology* 8, 1-7. doi: 10.1515/CHAR.2008.8.1.1
- Yuan, J., Flad, R.K., 2005. New zooarchaeological evidence for changes in Shang Dynasty animal sacrifice. *Journal of Anthropological Archaeology* 24, 252-270. doi: 10.1016/j.jaa.2005.03.001
- Yue, X.-P., Li, R., Xie, W.-M., Xu, P., Chang, T.-C., Liu, L., Cheng, F., Zhang, R.-F., Lan, X.-Y., Chen, H., Lei, C.-Z., 2013. Phylogeography and domestication of Chinese swamp buffalo. *PLoS One* 8. doi: 10.1371/journal.pone.0056552
- Zhang, H., Pajmans, J.L.A., Chang, F., Wu, X., Chen, G., Lei, C., Yang, X., Wei, Z., Bradley, D.G., Orlando, L., O'Connor, T., Hofreiter, M., 2013. Morphological and genetic evidence for early Holocene cattle management in northeastern China. *Nature Communications* 4. doi: 10.1038/ncomms3755
- Zhang, Z. 1998. *Jinning Shizhaishan* [Shizhaishan in Jinning], Yunnan Meishu Chubanshe, Kunming.
- Zhao, X. 1995. *Gansu Wushan Fujiamen shiqiang wenhua yizhi fajue jianbao* [Excavation report for the prehistoric culture site of Fujiamen in Wushan, Gansu Province]. *Kaogu* 4, 289-296, 304, 385.
- Zhou, B. 1999. *Shizhaocun yu Xishanping yizhi de dongwu yicun* [Faunal remains from Shizhaocun and Xishanping], In: *Zhongguo Shehui Kexue Yuan Kaogu Yanjiu Suo* [Chinese Academy of Social Sciences Institute of Archaeology] (Ed.), *Shizhaocun yu Xishanping* [Shizhaocun and Xishanping], *Zhongguo da bake quanshu chubanshe*, Beijing, pp. 335-339.
- ZSKY et al. [Zhongguo Shehui Kexue Yuan Kaogu Yanjiu Suo Anyang Gongzuo Dui, He, Y., Li, Z., Jiang, Y., Yue, Z.] 2015. *Henan Anyangshi Tiesanlu Yinxu wenhua shiqi zhigu zuofang yizhi* [The Yinxu culture period bone workshop site at Tiesanlu in Anyang]. *Kaogu* 8, 37-62.