A 115,000-year-old expedient bone technology at Lingjing, Henan, China

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Abstract

Activities attested since at least 2.6 Myr, such as stone knapping, marrow extraction, and woodworking may have allowed early hominins to recognize the technological potential of discarded skeletal remains and equipped them with a transferable skillset fit for the marginal modification and utilization of bone flakes. Identifying precisely when and where expedient bone tools were used in prehistory nonetheless remains a challenging task owing to the multiple natural and anthropogenic processes that can mimic deliberately knapped bones. Here, we compare a large sample of the faunal remains from Lingjing, a 115 ka-old site from China which has yielded important hominin remains and rich faunal and lithic assemblages, with bone fragments produced by experimentally fracturing *Equus caballus* long bones. Our results provide a set of qualitative and quantitative criteria that can help zooarchaeologists and bone technologists distinguish faunal remains with intentional flake removal scars from those resulting from carcass processing activities. Experimental data shows marrow extraction seldom generates diaphyseal fragments bearing more than six flake scars arranged contiguously or in interspersed series. Long bone fragments presenting such characteristics can, therefore, be interpreted as being purposefully knapped to be used as expediency tools. The identification, based on the above experimental criteria, of 56 bone tools in the Lingjing faunal assemblage is consistent with the smaller size of the lithics found in the same layer. The continuity gradient observed in the size of lithics and knapped bones suggests the latter were used for tasks in which the former were less or not effective.

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1. Introduction

Owing to their ubiquity in the archaeological record since 3.3 Myr (million years ago) (Harmand et al., 2015; Lewis and Harmand, 2016), stone tools have attracted much attention in studies of the technological changes associated with the evolution of members of our lineage. Despite use wear evidence for woodworking (Lemorini et al., 2014, 2019) and bone cutting (Domínguez-Rodrigo et al., 2005), the latter likely resulting from butchery and carcass processing activities, it remains unclear how and when lithic and organic technologies integrated the technical system of our ancestors and how they co-evolved. The origin and early developments of organic technologies remain difficult to apprehend because of their perishable nature. Pinpointing when osseous artefacts were incorporated in past technological system is nonetheless decisive in palaeoanthropological research because it identifies a significant shift in the way prehistoric human groups conceived faunal resources at their disposal. Specifically, it signals when animal skeletal element utility expanded to include the manufacture of implements in addition to their primary role for consumption, fat use or fuel. Earliest examples of osseous tools include bone digging implements from Southern Africa, an innovation attributed to *Australopithecus robustus* living in this region some 2.0–1.5 Myr ago as well as bone fragments bearing evidence of intentional flaking, battering and abrasion from Olduvai Beds I and II, East Africa, likely used by early members of our genus, *Homo*, in hide-working, butchery, digging, knapping, and hunting activities between ~1.8–1.0 Myr (Backwell and d'Errico, 2001, 2004; d'Errico and Backwell, 2009; Stammers et al., 2018; Pante et al., 2020). In the Southeast Asian Pacific Islands, shell scrapers were found at Trinil, Java (Joordens et al., 2015), in a formation linked to *Homo erectus* occupation some 450 kyr (thousand years ago). In Europe and the Levant, many Lower Palaeolithic antler, bone, and ivory tools were reported, yet most of them have been repeatedly called into questions (for a review see Villa and Bartram, 1996; Villa and d'Errico, 2001, and references therein). An indubitable tool type, however, consists of Acheulean bone handaxes. These tools are documented in Africa, at Olduvai Bed II, 1.7-1.15 Myr (Backwell and d'Errico, 2004), and at Konso, Ethiopia, in a context dated to ~1.4 Myr (Sano et al., 2020), in numerous sites dated between ~500–250 kyr from the Levant (Revadim Quarry; Rabinovich et al., 2012), Central Europe (Vértesszőlős; Kretzoi and Dobosi, 1990; Bilzingsleben; Mania and Mania, 2003), and Southern Europe (Torre in Pietra; Anzidei et al., 2001; La Polledrara; Anzidei, 2001; Santucci et al., 2016; Fontana Ranuccio; Naldini et al., 2009; Castel di Guido; Boschian and Saccà, 2015), as well as at the Bashiyi Quarry, Chongqing, China, in a context dated to ~170 kyr (G. Wei et al., 2017).

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Archaeologists usually make a distinction between two main bone tool categories: formal tools, i.e., faunal remains formally shaped into specific tool type with manufacturing techniques specific to osseous materials, such as grinding, gouging, scraping, notching, incising, etc., and expedient tools, i.e., bone fragments bearing little or no modifications and that were used as such (Klein, 2009; Kuhn, 2020). It is probable that activities attested since at least 2.6 Myr such as stone knapping, bone fracturing for marrow extraction (Madrigal and Blumenschine, 2000; Blumenschine and Pobiner, 2007), and woodworking (Lemorini et al., 2014, 2019) have allowed early hominins to recognize the technological potential of discarded carcass processing remains and equipped them with a transferable skillset fit for the manufacture and utilization of osseous material. Through trials and errors, Palaeolithic hominins would have been able to observe how bone responded to static and dynamic loadings, and embody this knowledge for immediate or future or use (*sensu* Ingold, 2002).

Identifying precisely when expedient tool use became commonplace in our evolutionary history remains a challenging task. Perhaps the most documented amongst this tool category are bone hammers and retouchers, i.e., knapping implements respectively used to remove flakes from lithic cores and to retouch the edges of stone tools. The earliest known instances of these tool types date back to 2.1-1.5 Myr at Olduvai Gorge, Africa (Backwell and d’Errico, 2004), to MIS18 (Marine Isotopic Stage) at Gesher Benot Ya’aqov in the Levant (Goren-Inbar, 2011), MIS13 at Boxgrove in Europe (Smith, 2013) and MIS5 at Lingjing in East Asia (Doyon et al., 2018, 2019). From MIS9, bone retouchers become an integral part of the cultural repertoire of Neanderthals (Moncel et al., 2012; Blasco et al., 2013; Daujeard et al., 2014, 2018; Moigne et al., 2016) and reach during MIS5 a high degree of standardization (Daujeard, 2007; Verna and d’Errico, 2011; Costamagno et al., 2018; Daujeard et al., 2018). Possible expedient tool types also include long bone shaft fragments with one or more edges modified by blows that generated flake scars present on the cortical and/or the medullar surface of the bone. In Europe, growing evidence for this technology appears during MIS9 at Gran Dolina, Spain (Rosell et al., 2011), Schöningen, Germany (Julien et al., 2015), and in Italy at Castel di Guido (Boschian and Saccà, 2015), Bucobello (Di Buduo et al., 2020), La Polledera di Cecanibbio and Rebibbia-Casal de’ Pazzi (Anzidei, 2001). In East Asia, similar tools were reported at Donggutuo, from a formation dated to 1.2-1.0 Myr (Wei, 1985) as well as at Panxia Dadong in a context dated between 250-130 ka, although the latter were produced on rhinoceros’ teeth (Miller-Antonio et al., 2000). Other instances of expedient

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bone tools from this region are reported in the literature but would require further assessment with modern methods to verify their chronology and the anthropogenic nature of the modifications (Xujiayao: Chia et al., 1979; Zhoukoudian Upper Cave: Pei, 1939; Yonggul cave: Sohn et al., 1991). It has been proposed that these tools were used for cutting soft animal tissues, vegetal fibers, or as wedges for splitting wood, antler and bone (Burke and d'Errico, 2008; Tartar, 2012; Hardy et al., 2014; Julien et al., 2015; Baumann et al., 2020; Kozlikin et al., 2020; Mateo-Lomba et al., 2020).

Despite this expanding data set, we are still lacking diagnostic criteria to distinguish faunal remains with flake scars that were intentionally modified for technological purposes from those resulting from carcass processing activities (see Research background). Our aim here is to contribute to the establishment of such criteria. The need for this study arose when analyzing the faunal assemblage excavated at Lingjing, layer 11, an archaeological context dated to 125-105 kyr (Nian et al., 2009) that has also yielded important archaic human remains (Li et al., 2017b). During the 2005-2015 excavation campaigns, one of us (LZ) isolated a number of faunal fragments bearing flake removal scars on both their cortical and medullar surfaces, and interpreted some of them as probable bone tools based on putative use wear recorded on some edges (Li and Shen, 2010). In 2016 two of us (LD, FD) were invited to re-examine these objects and reappraise a larger sample of faunal remains from the same context bearing flake scars and other modifications to test the hypothesis that they were used as tools. This led to the identification of the earliest known bone and antlers fragments used as retouchers and soft hammer from China (Doyon et al., 2018). Our research on the flaked specimens takes into account several lines of evidence: 1) a critical review of the site formation process; 2) a thorough quantification of the size and location of the flake removal scars on the putative bone tools; 3) a comparison with a selection of bone fragments isolated during the 2005-2015 excavations (*n* = 127), 4) a randomly selected sample of diaphyseal fragments (*n* = 100) coming from the same layer and recovered during the same excavation seasons (2005-2015), 5) an analysis of the entire faunal assemblage recovered from layer 11 during the 2017 campaign (*n* = 1260); 6) an experimental breakage of large mammals long bones aimed to quantify flake scars resulting from this activity. Our results suggest at least 56 faunal fragments can be interpreted as expedient bone tools, which expands the behavioural realm of the hominins who visited the Lingjing site during the Middle to Late Pleistocene transition.

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2. Research background

The technological use of carcass processing by-products by prehistoric hominins has been suggested and documented for more than a century. In the early 1900s, Dr. Henri-Martin experimented with the fracturing of horse long bones for marrow extraction and highlighted that some of the resulting bone fragments would have been fit for hide working or for transforming other kinds of material. Comparisons between his experimental results and the faunal remains from the Mousterian layers at La Quina, France, allowed him to suggest criteria to identify expedient osseous tools, such as the presence of use wear in the form of an unevenly distributed polish and worn edges smoothed by friction (Henri-Martin, 1910). Likewise, Raymond Dart (1957) hypothesized that instead of knapped lithics, Makapansgat *Australopithecus prometheus* used bone, tooth, and horn as hunting weapons. Despite his interpretation being later attributed to non-anthropogenic, taphonomic processes (Brain, 1981), Dart's work sparked an interest for studies aimed to document the natural and anthropogenic processes responsible for the modification of faunal remains. We have since gained a clearer understanding of the multiple agents that can cause the post-mortem flaking, cracking, and fragmentation of osseous remains, including gnawing, chewing, fracturing, and digestion by mammal and reptile predators, carnivores, rodents, herbivores, or birds (Binford, 1981; Haynes, 1983; Villa and Mahieu, 1991; Pérez Ripoll, 1992; Hockett, 1996; Villa and Bartram, 1996; Capaldo, 1998; Benson et al., 2004; Villa et al., 2004; Njau and Blumenschine, 2006, 2012; Margalida, 2008; Ardèvol and López, 2009; Marín Arroyo et al., 2009; Cáceres et al., 2011; Hutson et al., 2013; Bourdillat, 2014; Lloveras et al., 2014; Sanchis Serra et al., 2014; Armstrong, 2016), fracturing by hominins for marrow and bone grease exploitation (Bunn, 1981; Gifford-Gonzalez, 1991; Outram, 2001; Pickering and Egeland, 2006; Blasco et al., 2014; Grunwald, 2016; Marom, 2016; Morin and Soulier, 2017; Stavrova et al., 2019; Morin, 2020; Vettese et al., 2020a, 2020b), trampling, root etching, weathering, exposure to heat and cold, sediment pressure, deposition in alkaline environment (Brain, 1967, 1981; Behrensmeyer, 1978; Binford, 1981; Lyman, 1984, 1994; Behrensmeyer et al., 1986; Haynes, 1991; Blasco et al., 2008; Costamagno et al., 2010; Morin, 2010; Madgwick, 2014; Reynard, 2014; Fernández-Jalvo and Andrews, 2016), etc.

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When osseous technology is concerned, and leaving aside bone retouchers, which have received much attention (e.g., Verna and d'Errico, 2011; Mallye et al., 2012; Moncel et al., 2012; Mozota Holgueras, 2012; Blasco et al., 2013; Moigne et al., 2016; Costamagno et al., 2018; Daujeard et al., 2018; Doyon et al., 2018; Hutson et al., 2018a; Doyon et al., 2019;

Pérez et al., 2019 and references therein), the identification of expedient bone tools still heavily relies on the presence of use wear associated with flaking scars (Hardy et al., 2014; Julien et al., 2015; Baumann et al., 2020; Kozlikin et al., 2020; Mateo-Lomba et al., 2020), accidental fracture and crushing of the working edges and surfaces (Burke and d'Errico, 2008; Tartar, 2012; van Kolfschoten et al., 2015; Hutson et al., 2018b), or a combination of these factors (Backwell and d'Errico, 2001, 2004, 2008; Stammers et al., 2018). Faunal remains bearing only flake scars, however, have been somewhat overlooked. In recent years, their description was mainly concerned with flakes produced in the context of osseous tool blank extraction (see Christensen and Goutas, 2018; and particularly Goutas and Christensen, 2018). One noticeable exception remains the experimental work on elephant bones and the archaeological comparison with the assemblage from Olduvai Gorge, Tanzania, where the number of flake removals, their location and dimensions were systematically recorded (Backwell and d'Errico, 2004). In the present paper, we extend the approach proposed by these authors with the aim to distinguish between intentionally modified expedient osseous tools and marrow exploitation by-products from the Lingjing site, Henan, China.

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3. Archaeological context

The Lingjing site was identified in 1965 when microcores and microblades lithic technologies as well as mammalian fossils were collected on the surface of a field (Zhou, 1974; Chen, 1983) in the northeast Xuchang County, Henan Province (34˚ 04' 08.6" N, 113˚ 40' 47.5" E, 117masl). The site is located in a transitional area between the eastern foothills of Songshan Mountains and the Huang-Huai Plain, on the southern fringes of the North China Plain, some 120km south of the Yellow River (Fig. 1). An active water spring is present in the southern portion of the site and a water cistern was built over its opening in 1958 (Li et al., 2020).

From 2005 to 2017, a *c.* 550m^2 area was excavated by one of us (LZ, in collaboration with Dr. Li Hao, Institute of Vertebrate Paleontology and Paleoanthropology, Beijing, in 2017) at a depth averaging *c.* 9m. Excavations have been halted since 2018 owing to the construction of an Archaeological Site Museum above the deposit, an infrastructure project which aims to put on display the human fossils and archaeological remains recovered at this locality (see Zhao and Doyon, 2020 for a definition of this type of Museum). During the excavations, eleven geological layers were identified and three archaeological horizons yielded cultural remains. The uppermost layers 1-4 are Holocene in age and were identified over the entire excavated surface. The archaeological remains recovered from these layers were exclusively found along the norther limit of the investigated area, and only consist of a few isolated, fine pottery sherds, none of which could be refitted to one another. Decors on their outer surface suggest a cultural attribution to a period spanning from the Yangshao Neolithic to the Shang-Zhou Bronze Age (~6.5 – 2.5 kyr). Layer 5 and the spoil heap left by well diggers in 1958 were identified solely in the southern portion of the site. This layer and the sediments originating from it yielded a rich microcore and microblade industry made of high-quality black chert (Li et al., 2014; Li and Ma, 2016; Z. Li et al., 2018), a small amount of quartz tools, some very fragile, thick, crude, simple-shaped pottery sherds with plain surfaces (Li et al., 2017a), burnt and unburnt faunal remains, charcoals, ostrich egg shell fragments, including one transformed into a perforated pendant, and the oldest sculpture discovered in China, a bird figurine carved from a mammalian long bone fragment that had likely been heated in an anaerobic environment prior to shaping the artwork (Li et al., 2020). The ^{14}C dating of burnt bones, charcoals and charred residues recovered on the pottery sherds suggests three human occupations spanning from the LGM to the Pleistocene-Holocene transition, i.e., a first occupation between ~13.8 – 13.0 kyr by Late Glacial hunter-gatherers bearing microlithic technologies who made the bird figurine, and two human occupations by ceramics users between ~11 – 10 kyr and ~9.6 – 8.7 kyr respectively. Layers 6 to 9 were identified over the whole excavated area. They were entirely sterile and represent a *c.* 4.5m hiatus between the LGM human occupations from layer 5 above and the early Late Pleistocene archaeological horizon below.

Layers 10 and 11 were deposited during the early Late Pleistocene. Two OSL samples collected at the base and in the upper half of layer 10 were dated to ~102 ± 2 and ~96 ± 6 kyr respectively. The five OSL samples from layer 11 yielded ages spanning from ~105 kyr at the top to ~125 kyr at the bottom of the layer (Nian et al., 2009). These ages correspond to the early MIS5, i.e., MIS5e to MIS5d, and to the last interglacial paleosol S1 in the Chinese Loess Plateau sequence. In 2007 and 2014, 45 fragments of archaic human crania were recovered *in situ* in layer 11. Aside from three isolated pieces, all fragments were refitted into two individual crania (Li et al., 2017b), named Xuchang (XUC) 1 and 2 after the County in which the site is located. Morphological analysis of the crania identifies a mosaic of anatomical traits that remains undocumented to this day in the Old World. They exhibit ancestral features reminiscent of early Middle Pleistocene eastern Eurasians, others derived and shared by archaic and modern Late Pleistocene individuals as well as a combination of traits at the midoccipital area and the temporal labyrinths usually observed only in Neanderthal populations. This peculiar mix suggests complex intra- and interregional population dynamics between western and eastern Eurasian hominins prior and during the Middle to Late Pleistocene transition. It has been suggested these two individuals could be Denisovans (Martinón-Torres et al., 2017) although DNA and proteomic analyses are still missing to test this hypothesis. From a palaeopathological perspective, both XUC1 and XUC2 present external auditory exostoses, i.e., a dense bony growth protruding in the external auditory canal that implies conductive hearing loss (Trinkaus and Wu, 2017).

The rich lithic assemblage from Lingjing, layers 10 and 11, amounts to more than 15,400 remains. Quartz and quartzite are the two predominant raw materials used for the manufacture of tools. Alterations of the cortex still present on lithic artefacts, estimation of the original size of the river pebbles selected for knapping, and outcrops survey of the Ying River suggest the prehistoric occupants at Lingjing exploited raw material found within 10km from the site (H. Li et al., 2019). Differences in selected raw material are documented between layer 10 and 11. While the percentage of quartz artefacts declines from layer 11 to 10, this latter layer attests for a diversification of raw material, with a notable increase of quartzite, sandstone and basalt (Zhao et al., 2019). All products and by-products of the operational sequence are represented in the lithic assemblage. The reduction sequence is mainly oriented towards the detachment of flakes and production of chunks that are later retouched and shaped into tools. A fifth of the cores are of discoidal type, the remaining cores correspond to expedient debitage following a number of knapping strategies (for a distinction between formal and expedient cores, see Wallace and Shea, 2006). This pattern indicates some degree of behavioural flexibility and a proximal, problem-oriented response to satisfy needs requiring the use of lacerating edges (H. Li et al., 2019). The shaping of blanks into tools is predominantly performed by free-hand hard hammer percussion (≈75%), although organic soft hammer percussion and pressure retouch were also documented on >20% of the implements (H. Li et al., 2019). The lithic toolkit primarily includes scrapers, notches, denticulates, borers, and points. A few burins and backed pieces were also identified. Rare instances of heavy-duty tools such as choppers and spheroids were documented (H. Li et al., 2019; Zhao et al., 2019). Use wear analysis suggests some tools were used at the site (Li and Shen, 2011). Lithic refitting attempts indicate stone tools were not submitted to significant horizontal or vertical post-depositional disturbances (Zhao et al., 2019).

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Ideal post-depositional and fossilization conditions allowed to recover from layer 10 and 11 a rich faunal assemblage surpassing 50,000 remains (Li and Dong, 2007; Dong and Li, 2009; van Kolfschoten et al., 2020). The carnivore guild is diverse and includes, in decreasing order, *Pachycrocuta* cf. *sinensis*, *Panthera* cf. *tigris*, *Ursus* sp., *Vulpes* sp., *Canis* cf. *lupus*, and *Meles* sp. Dozens of coprolites from medium-sized carnivores, likely hyena, were recovered at the site (Wang et al., 2014, 2015). The herbivore guild is dominated by equids, i.e., *Equus hemionus* and *Equus przewalskii*, and bovids, i.e., *Bos primigenius*. In decreasing order, the herbivores also include *Coelodonta antiquitanis*, *Sus lyddekeri*, *Cervus elaphus*, *Procapra przewalskii*, *Cervus* (*Sika*) sp.. Other taxa, e.g., *Palaeoloxodon* sp., *Dicerorhinus mercki*, *Hydropotes pleistocenica*, *Elaphurus davidianus*, and *Sinomegaceros ordosianus*, are present but in very small proportions, i.e., usually less than five elements per species (van Kolfschoten et al., 2020). Modifications by carnivore, e.g., pits and scores as well as surface etching owing to digestion, were seldom observed on the faunal remains (<1%), which suggests they played a limited role in the accumulation of the assemblage (Zhang et al., 2009, 2011a, 2011b, 2012; Doyon et al., 2018, 2019). The main anthropogenic modifications recorded on the faunal remains consist of cut marks generated during butchery activities, and percussion scars likely resulting from the breaking of diaphysis to extract bone marrow. The skeletal element profiles dominated by body parts with lower nutritional values, the mortality patterns of the main prey species, i.e., equids and bovids, represented exclusively by prime-adult individuals, and bone surface modifications demonstrate the importance of the Lingjing site in subsistence activities, namely for the hunting of prey and carcass processing (Zhang et al., 2009, 2011a, 2011b, 2012).

A few dozen bone retouchers were identified, which were grouped into two strategies (Doyon et al., 2018, 2019). The first strategy encompasses 85% of the specimens, and consists of selecting bone fragments and using them as such for a single retouching event to sharpen the dull edges of stone tools likely used in butchery activities. The second strategy involves selecting weathered cervid's metapodials, marginally modifying them by flaking to produce an elongated tool with improved ergonomic, transportability and efficiency, and intensively, and recurrently use them for retouching stone tools. Alongside the bone retouchers, a single dear antler bears traces of use as soft hammer (Doyon et al., 2018). Surface modifications observed on a few faunal fragments and their experimental replications suggest some skeletal remains were used in passive and active pressure flaking activities (Doyon et al., 2019),

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which support Li’s et al. (2019) contention for an independent origin of pressure flaking in China *c.*115 ka, i.e., 40,000 years prior to the earliest occurrence of similar behaviour in Southern Africa (Mourre et al., 2010; d’Errico et al., 2012; de la Peña et al., 2013).

The use of bone in knapping activities is not restricted to the manufacture and maintenance of stone tools. Numerous bovids and equids metapodia display a combination of alterations, i.e., crushing and flaking on the distal condyles as well as evidence of fresh bending fractures resulting in the sectioning of the distal epiphysis and the main shaft. These modifications have been interpreted as evidence for the intentional selection and use of bovids and equids metapodia for knapping mammal long bones in an attempt to extract the marrow it contains (van Kolfschoten et al., 2020). Interestingly, this behaviour has been also reported at the Schöningen 13 II-4 site, i.e., the Spear Horizon (van Kolfschoten, 2014; Serangeli et al., 2015; van Kolfschoten et al., 2015; Hutson et al., 2018b, Bonhof and van Kolfschoten, 2021), which is dated to *c.* 300 ka BP.

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Perhaps the most unexpected find from layer 11 consists in the identification of two fragments of medium to large-size mammal rib bearing respectively 10 and 13 sub-parallel engraved lines. Microscopic analysis indicates these lines were made when the fragments were already weathered, therefore rejecting the hypothesis that they could represent butchery cut marks. Analysis of red residues identified in and between the lines engraved on one specimen demonstrates the presence of red hematite, interpreted as evidence of smearing ochre over the pattern to make it more visible (Z. Li et al., 2019).

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Formation processes of layers 10 and 11 were investigated with magnetic susceptibility, sedimentology, X-ray fluorescence (XRF) and X-ray diffraction (XRD) as well as the orientation and plunge of lithic artefacts. Results suggest a slow deposition rate with limited to low energy flow across the site. Layer 11 likely formed in a relatively stable, close, oxygen-poor environment; the deposition of layer 10 occurred at a time when the local water table was subjected to more frequent rises and falls (H. Li et al., 2018). These conclusions are supported by the taphonomic analysis of the faunal assemblage. The faunal remains from layer 10 were mainly affected by weathering; those from layer 11 show significantly more elements with surfaces covered with concretions and altered by root-etching (Doyon et al., 2019). Palaeoenvironmental reconstruction from pollens recovered in hyena coprolites suggests a grassland-dominated vegetation with a mosaic of scattered, mixed forests (Wang et al., 2014, 2015). This environment, combined with the presence of an active water spring surely attracted both animals and humans throughout the early Late Pleistocene, as attested by the uninterrupted vertical distribution of lithic and faunal remains from the lower half of layer 10 to the bottom of layer 11 (H. Li et al., 2018).

4. Material and methods

4.1 Archaeological remains

The faunal assemblage from Lingjing, layer 10 and 11, is curated at the Henan Provincial Institute for Cultural Relics and Archaeology, Zhengzhou, China. From 2005 to 2016, excavation methods at the site involved removing the sediments with curved-tipped trowels, 3D-plotting faunal and lithic remains with maximum length greater than 2.5cm, and sieving sediments through a 2mm mesh. Both lithic and faunal remains were cleaned using soft brushes under running water. When present, concretions were not removed from the faunal remains. In 2017, the same protocol was implemented, although piece plotting was also performed for fragments measuring 1–2.5cm in length. The material considered in the present study comes exclusively from layer 11 and amounts to 1,487 faunal remains. It includes (1) a sub-sample of 127 bone fragments isolated by one of us (LZ) during the 2005-2015 excavations, and analyzed by two of us (LD, FD) in 2016. The specimens comprised in this sample, henceforth PBT (Potential Bone Tools), bear features, i.e., flake scars, polish, impacts, morphology, that have attracted the attention of the excavator and convinced him they could have been expedient tools; (2) a randomly-selected sub-sample of 100 long bone fragments from the same excavation years, analyzed by two of us (LD, FD) in 2016. This sample, henceforth RCS (Restricted Control Sample), was selected with the purpose of verifying whether PBT or some specimens within PBT stand out in some respects when compared to RCS or simply represent an extreme in variation of the modifications present in the assemblage; (3) the entire faunal assemblage yielded by the 2017 excavation of layer 11, i.e., 1,260 bone fragments, analyzed by one of us (LD) in 2018. Being composed of all faunal remains recovered that year, including 1-2,5cm-long fragments, this assemblage composed mainly of diaphyseal fragments (>85%), henceforth CCS (Complete Control Sample), is particularly appropriate for comparison with bone fragments stemming from our experiments since we recovered all bone fragments, including those smaller than 2.5cm.

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Each specimen was first examined with a magnifying glass with incident light. Anthropogenic modifications were distinguished from natural ones based on published criteria, with a particular attention on the natural and anthropogenic processes that could produce flaking scars on faunal remains (Behrensmeyer, 1978; Myers et al., 1980; Binford, 1981; Shipman and Rose, 1983, 1988; Lyman, 1984, 1994; Morlan, 1984; Behrensmeyer et al., 1986; Noe-Nygaard, 1987, 1989; Villa and Mahieu, 1991; Pérez Ripoll, 1992; Patou-Mathis, 1994; Fisher Jr, 1995; Villa and Bartram, 1996; Villa et al., 2004; Pickering and Egeland, 2006; Galán et al., 2009; Bourdillat, 2014; Vercoutère et al., 2014; Fernández-Jalvo and Andrews, 2016; Fourvel, 2017). When identifying the cause for specific bone surface modifications proved difficult, microscopic observations were conducted using a Leica Wild M3C stereomicroscope equipped with a Nikon CoolPix 900 digital camera at magnifications ranging from 4–40x. Selected specimens were photographed with a Canon PowerShot 100 and a Nikon D300 AF equipped with a Micro Nikkor 60 mm f/2.8D lens cameras.

Morphometric data, i.e., maximum length, width, thickness, and cortical thickness of the bone fragments, were collected using a digital caliper. The following variables were recorded for specimens with flake scars: number of scars, their location (cortical or medullar surface, distal or proximal, one side or both sides), arrangement (isolated, contiguous, interspersed), and the breath of each flake scar longer than 0.5mm. We included in the contiguous flake scar category adjacent and overlapping removals. Interspersed series of flake scars refer to two or more sets of contiguous flake scars separated by an unmodified portion of the diaphyseal fragment edge.

4.2 Experimental program

In an attempt to establish if marrow extraction activities could produce a flaking pattern akin to that observed on the faunal remains from Lingjing, we implemented an experimental protocol that aimed to fracture large mammal long bones to expose the marrow. We selected six long bones from an adult *Equus caballus*: two humeri, two tibiae, one femur, and one radius. The choice of taxon was motivated by the fact that equids constitute the majority of the herbivore guild at Lingjing. The horse was killed in Eastern Europe six days prior to the experiment, and kept in a refrigerated room at 4–5˚C before being shipped to the Nouvelle-Aquitaine region by refrigerated truck the day before the experiment. The meat was removed overnight by a professional butcher using modern tools and the bones were received with scraps of meat and connective tissues still attached. They were fractured without previously removing the periosteum and adhering soft tissues.

The fracturing experiment took place on the University of Bordeaux campus. A 6m^2 woven plastic tarp was placed on a grassy ground to ease the recovery of bone fragments. Two trained experimenters broke the long bones: a 35-40 years-old male, with eight years of experience (henceforth, Series 1), and a 60-65 years-old male, with ~35 years of experience (henceforth, Series 2). Their aim was to produce longitudinal diaphyseal fragments while exposing the marrow. They were free to choose the hitting points and change them throughout the experiment. The bone was resting on a limestone anvil and was secured with one hand holding an epiphysis. With a 1.85kg beach pebble serving as hammerstone in the other hand, the experimenters produced a series of blows on the diaphysis. Two techniques were used. For Series 1, the experimenter started by hitting multiple times a single point on the metaphysis, i.e., the transitional zone at which the diaphysis and epiphysis meet. When cracks started to appear, he did the same on the opposite metaphysis to expand the fracture from the other end of the bone and, then, exposed the marrow by hitting the diaphysis on its mid-section. This procedure was applied on one specimen of each skeletal element. For Series 2, the experimenter hit the diaphysis with a series of rapid, successive blows along the diaphysis from one metaphysis to the opposite. If the marrow was not exposed following the first series, he turned the bone to hit it on a second surface. This procedure was applied to one humerus and one tibia. Although the blows applied to the tibia produced longitudinal fractures, the periosteum prevented the opening of the diaphysis, which was achieved by hitting the bone directly on the anvil. The batting technique was not used in our experiment. This choice was motivated by the fact that no blocks suitable for this fracturing method were found at the site.

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Throughout the experiment, notes were taken by a third participant (LG) on recording sheets where the anterior, posterior, medial, lateral, proximal and distal aspects of each element were illustrated. The information recorded includes the location of the percussion, the number of blows as well as any qualitative observations made by the experimenters in the process. Photographs and video recording were done with a Canon PowerShot G7 X Mark II camera. After the breakage of each bone, all bone fragments and epiphyses were collected in a single bag associated with an identification code indicating the date of the experiment, the element, and the series' number. Broken bones were cleaned separately to avoid loss of small fragments and/or identification codes at the *Laboratoire de Préparation des faunes* (UMR5199 PACEA, University of Bordeaux). This experimental reference collection, curated at UMR5199 PACEA, is available for studying and teaching purposes.

The broken bones were separated into four categories: epiphysis, diaphyseal fragments, flakes, and splinters. Diaphyseal fragments correspond to large bone pieces preserving at least 10% of the shaft circumference, where both cortical and medullar surfaces are present and that can be refitted, at least mentally, to other fragments. Flakes refer to medium-sized remains, usually larger than 2cm, that were detached either from the cortical or the medullar surface. The shaft circumference cannot be estimated from this category and, unless bearing clear anatomical features or a bulb of percussion and/or a morphology matching a flake scar on a diaphyseal fragment, they prove difficult to refit with other pieces. Splinters consists of small bone pieces, usually less than 2cm in length. They outnumber any other categories and sometime preserve small remains of cortical and/or medullar surfaces indicating their original position within the diaphyseal section. They are too small to allow their refitting to any other pieces. Epiphyses were not considered in the present study. Morphometric and qualitative data collection on the cleaned diaphyseal fragments, flakes, and splinters followed the procedure described for the archaeological samples. In addition, for flakes and splinters, we established their original position relative to the cortical thickness (cortical, medullar surface, or unknown), and recorded the presence of the percussion bulb.

Statistical tests and data representation were performed in R-CRAN (R Development Core Team, 2008). The maximum lengths recorded on diaphyseal fragments from each sample were compared with the Kruskal-Wallis non-parametric test because the values were not normally distributed, therefore preventing the use of an ANOVA. Thickness values were normally distributed and difference between samples were tested with Student's *t*-test. An ANOVA complemented with a pairwise comparison based on Tukey HDS was applied to test for significance differences in the number of flake scars recorded on bone fragments from each sample.

5. Results

5.1 Experimental data

On average, ~38 blows were necessary to expose the medullar cavity (Fig. 2). This average is reduced to 25 blows (minimum: 16 blows for the humerus from Series 2; maximum: 34 blows for the tibia from Series 2) when the femur and radius from Series 1 are not considered, which respectively required 62 and 65 blows to access the marrow. Compared to fracturing experiments done on cattle long bones (e.g., Blasco et al., 2014; Stavrova et al.,

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2019; Vettese et al., 2020b), more blows were required to expose the medullar cavity, which can be explained by the more invasive and dense spongy bone present in horse's long bones. The final blow performed on the tibia from Series 2 resulted in the high fragmentation of its diaphysis. Remains from the fracturing of Series 2's tibia are left out of the presentation of the experimental results; they are, however, included in the comparison with the archaeological samples (see Section 5.3).

Both methods used to break the bones produced comparable number of fragments, flakes and, to a lesser extent, splinters (Tab. 1). Percussion bulbs are present on 35.71% of the flakes and on 8.66% of splinters (μ = 11.73%). When the original position of flakes and splinters within the diaphyseal section is examined, both categories show an average of 14.23% specimens detached from the medullar surface. Flakes are almost six times (5.75 to 1) more likely to be detached from the cortical surface of the bone than from the medullar one. Likewise, splinters are twice (2.17 to 1) more likely to detach from the cortical surface. This difference is mainly due to the high proportion of splinters of unknown origins (55.12%). When size is considered, and despite a greater dispersion around the mean, Series 1 has consistently produced fragments with lengths on average three times longer than their widths. The humerus' fragments from Series 2, on the other hand, are on average twice as long as they are large. This result suggests it would have been possible for Palaeolithic hominins to apply both knapping methods in the event they wanted to produce elongated blanks while simultaneously exploiting bone marrow.

Half of the diaphyseal fragments (18 out of 33) bear flake scars (Tab. 2). In almost 90% of the cases, fragments with clear flake removal scars also bear indubitable impact scars, i.e., small depressions or crushing of the compacta produced by the protrusion of the object used to hit the bone shaft, and eventually break it and expose the medullar cavity to access the marrow. When the location of the flake scars is considered (Tab. 3), they are more often present on the cortical (48.75%) than on the medullar surface (30.00%) or on both (21.25%). They also occur mainly on the distal and/or proximal edges of the fragments (51.25%) than on the sides (28.25%). This pattern is characteristic of comminuted fractures resulting from high-impact and high-energy compressive trauma on the bone diaphysis (Garnavos et al., 2012). It has been observed in other fracturing experiment, e.g., the breaking of elephant long bone through a variety of techniques (Backwell and d'Errico, 2004). Flake removals on the medullar surface of the bone are systematically associated with percussion notches

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presenting, on the medullary view, multiple superimposed conchoidal scars (overlapping notches sensu Blasco et al., 2014; or percussion notches with inner conchoidal scars sensu Vettese et al., 2020a). Repeated impacts on a small area of the cortical surface accelerate the detachment of flakes in, or near, the corresponding area on the medullar surface.

When the arrangement of flake scars is considered, almost two thirds of them (66.25%) are isolated. It is rare to count more than two isolated flake scars on a single diaphyseal specimen. Only two diaphyseal fragments deviate from this rule and present four and seven flake scars; they respectively come from the fracturing of the femur and radius, i.e., the two bones from Series 1 that required the greatest number of blows to open the medullar cavity. Our experiment suggests marrow exploitation can produce contiguous flake scars 28.75% of the time. Contiguous flake scars vary between two to three per fragments. Only one diaphyseal fragment from Series 2's tibia bears six contiguous flake scars at its distal end, i.e., five on the cortical and one on the medullar surface. Interspersed series of flake scars were observed only on one specimen (5%), i.e., the radius from Series 1, which presents three contiguous flake scars at its distal end and a single flake scar on its side, near the distal end.

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5.2 Archaeological data

The faunal remains from Lingjing generally present an excellent state of preservation. The main taphonomic modification recorded on the faunal assemblage from layer 11 is root etching (Tab. 4); this damage is observed on 36.31% of the overall remains, and in somewhat greater proportions when considering only diaphyseal fragments bearing flake scars (44.93%). No traces of abrasion were observed on the specimen included in this study. Modification caused by carnivores are rare (1.08%, or 16 specimens out of 1487). The most common anthropogenic modification consists of butchery cut marks (18.51%). A few impact scars reflecting deliberate bone fracture were also identified (2.38%). With the exception of four specimens from the PBT, none of the other diaphyseal fragments with flake scars bears impact scars that could be interpreted as resulting from bone fracturing activities. The degree of polish of the surface of faunal remains is quite variable and substantially higher on the PBT specimens compared to the other two archaeological samples, i.e., RCS and CCS (Tab. 4).

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All samples differ significantly from one another when the size of the fragments is considered (Kruskal-Wallis $\chi^2 = 174.04$, df = 2, $p < 0.000$). This difference is accentuated by

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the underrepresentation of small fragments in PBT and RCS compared to CCS, which can be explained by the change in recovery procedure of very small fragments implemented in 2017 (Fig. 3, Tab. 2). In all archaeological samples, however, diaphyseal fragments with flake scars are significantly thicker than those without flake scars (Tab. 4; $t = -7.3323$, df = 166.42, $p < 0.000$), and their cortical thickness indicates most of them comes from medium to large-size mammal long bones. These fragments often also have lengths that nears three times their width.

5.3 Comparison between archaeological and experimental diaphyseal fragments

Striking differences appear when comparing archaeological and experimental material. Impact scars and flake scars are systematically associated on our experimental, diaphyseal fragments (Tab. 2). Such an association is rarely observed on the faunal remains from Lingjing. The location and arrangement of flake scars on the experimental fragments show a remarkable similarity with those recorded on the CCS (Tab. 3). These two sub-samples are also similar in the proportion of faunal remains by size class in general, and the proportion of diaphyseal fragments with flake scars by size class in particular (Fig. 4). The specimens from the PBT and RCS samples feature a substantially larger proportion of specimens with bifacial flake scars, respectively 54.5% and 33.3%, than what is observed both on the experimental material and the CCS, respectively 22.2% and 17.6%. The presence of bifacial flake scars on the lateral edges of archaeological specimens is much higher than on their experimental counterpart and 68.6% of the diaphyseal fragments from the PBT and RCS show a pattern of contiguous or interspersed series of flake scars. Such arrangement is extremely rare on the experimental specimens.

When the number of the flake scars per specimen is analyzed, significant differences are observed (Fig. 5a). These differences are especially marked between PBT and all other samples ($F_{(3,150)}=22.78$; $p < 0.000$), both archaeological (PBT:RCS $p < 0.000$; PBT:CCS $p < 0.000$) and experimental (PBT:EXP $p < 0.000$). No significant pairwise differences are observed between RCS, CCS and the experimental samples as illustrated by their overlapping values (Fig. 5a; RCS:CCS $p = 0.998$; RCS:EXP $p = 0.796$; CCS:EXP $p = 0.800$). Finally, a substantial overlap is also observed for all samples in the breath of the flake scars regardless of their location or arrangement (Fig. 5b).

6. Discussion

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We argue that a subsample of the remains composing the PBT and RCS must be interpreted as expedient bone tools. This diagnosis is based on several lines of evidence. The low percentage of carnivore modifications and the high proportion of remains with cut marks suggest Palaeolithic hominins were the main agent for the accumulation of the faunal assemblage recovered in layer 11 (Zhang et al., 2011a, 2011b; Doyon et al., 2018, 2019; van Kolfschoten et al., 2020). The uninterrupted vertical distribution of both lithic and animal remains, the low plunge of the lithic artefacts (H. Li et al., 2018), and evidence from lithic refitting (Zhao et al., 2019) argue for a continuous deposition of the archaeological remains between 125 and 105 kyr with minimal post-depositional disturbance. Between 100 and 13.5 kyr, the site appears to have been abandoned, perhaps owing to the drying of the water spring. This change in environmental conditions favoured the accumulation of a ~4.5m loess layer sealing the early late Pleistocene occupation and protecting it from dynamic processes that could have modified the underlying archeological assemblage.

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Aware that some peculiar-looking faunal fragments had been isolated during the 2005-2015 excavations owing to their polished surfaces and the presence of flake scars, it was imperative to compare these with a larger sample, i.e., a random selection from the same excavation years and the entire assemblage recovered from layer 11 in 2017. Size difference between the fauna from 2017 and 2005-2015 highlights a bias attributed to the change in recovery methods implemented in 2017, a modification of sampling procedure that had the effect of significantly increasing the proportions of small faunal remains. When both sub-samples from the 2005-2015 excavations were compared, i.e., PBT and RCS, the proportion of fragments with flake scars diminishes from 60.6% in PBT to 44.0% in RCS. Many of these fragments present contiguous, or interspersed series of flake scars. This pattern is even more striking when we consider that only 1.3% of the faunal remains from the 2017 excavations bear flake scars, or 8% when leaving aside the 1,047 remains measuring less than 25mm in length. In the 2017 sample, flake scars are predominantly present on the cortical and medullar surfaces, and at the proximal and/or distal ends of these fragments. It would therefore appear that the difference in excavation methods cannot, in and of itself, explain the differences in the proportion of diaphyseal fragments with flake scars or the location of these scars on the faunal remains.

Mortality patterns, skeletal element representation and anthropogenic modification on the faunal remains (Zhang et al., 2009, 2011a, 2011b, 2012), as well as the osseous and lithic toolkit (Doyon et al., 2018, 2019; H. Li et al., 2019; Zhao et al., 2019; van Kolfschoten et al., 2020) are coherent with the interpretation according to which Lingjing was repeatedly used as a kill/butchery site during the early Late Pleistocene. In order to explore anthropogenic activities that could have resulted in the production of flake scars on faunal fragments, it became necessary to assess to what extent marrow extraction could generate such a pattern. Our experimental results show that fracturing long bone diaphysis to expose the medullar cavity can produce diaphyseal fragments with flake scars half of the time. However, these scars are found in limited number, rarely exceeding four per fragments, and they seldom occur contiguously nor in interspersed series. When both the proportions of faunal fragments in general, and those bearing flake scars in particular, are considered, our experimental data closely matches the pattern emerging from the CCS. Likewise, all the specimens with contiguous flake scars from the RCS fall within the range of variation of our experimental data, both in terms of number of flake scars per item and their breath. The most important difference between the experimental and the archaeological samples refers to the co-occurrence of impact scars and flake scars. These two anthropogenic modifications were recorded on ~90% of the experimental sample but were only seldom observed on archaeological specimens. Finally, we do not find in our experimental material the high prevalence of long bone fragments observed in the PBT sample with numerous contiguous and interspersed series of flake scars. Considering the sedimentary context, the rarity of carnivore modifications on all examined samples and the fact that experimental deliberate flaking of bone fragments of the same type and size produce flake scars comparable to those observed on the archeological specimens (ETTOS, 1985; Vincent, 1993; Romandini et al., 2015; Baumann et al., 2020), we must conclude that a subsample of PBT and RCS should be interpreted as composed by bone fragments that were deliberately modified through percussion by Lingjing hominins. The most probable goal of this behaviour was that of using the resulting retouched bone fragments as tools.

The comparison between the archaeological and experimental data suggests a number of qualitative and quantitative criteria could help distinguish faunal remains with flake scars that were intentionally modified for technological purpose from those that result from carcass processing activities such as marrow exploitation, even in the absence of a well-developed use wear polish. From a contextual perspective, if carnivores had a limited role in the accumulation, or attrition (e.g., Wadley, 2020), of the faunal assemblage and if this assemblage was not subjected to important dynamics processes after its deposition, a low percentage in the co-occurrence of marrow extraction impact scars and flake removal scars on diaphyseal fragments from medium to large-sized mammal long bones is a good indicator that some of these specimens may have been intentionally shaped by direct percussion. From a quantitative perspective, this interpretation can be further supported when specimens bear more than six flake scars and when their arrangement show a high frequency of contiguous, and/or interspersed series of, scars. Although most of the fragments in our experimental sample bore four scars or less, we err on the side of caution and extend this threshold to include values included between μ and $\mu + 1\sigma$. Our conclusions are almost entirely compatible with those reached by Backwell and d'Errico (2004). Their comparison between a large sample from Olduvai and an experimental sample knapped on elephant bones led these authors to suggest that diaphyseal fragments "bearing five or more flake scars, some of which are contiguous, with one or more anomalously invasive [i.e., larger than 40mm in breath] primary removals" (Backwell and d'Errico, 2004, pp. 148, 150) were likely to have been intentionally modified into expedient tools. In our analysis, however, the breath of flake scars doesn't seem to be a good indicator for the intentional shaping of diaphyseal fragments. This may be due to the fact that Backwell and d'Errico experimented on elephant bones, which allows the development of more invasive flake scars. Simply put, flake scars size doesn't seem to matter as much as their frequency and arrangement.

Based on these criteria, we can interpret 56 diaphyseal fragments, i.e., 49 of the PBT and 7 in the RCS, from the Lingjing, layer 11, faunal assemblage considered in the present study as having been intentionally modified by direct percussion (Figs. 6-7, SI Tab. 1). Their compact bone thicknesses measure 14.6mm on average ($\sigma = 5.51$mm), and their maximum lengths are usually 2.72 times longer than their widths ($\sigma = 0.87$). More than three quarters of them (78.6%) show evidence of fresh fractures which suggests they were modified while the bone was still green. Two thirds of them (67.9%) bear flake scars on both their cortical and medullar surfaces. The number of flake scars per specimens varies from seven to 24 ($\mu = 12.8$; $\sigma = 5$). The lateral edges of the diaphyseal fragments are often modified (cortical surface: 71.4%; medullar surface = 42.9%) with either contiguous (51.8%) or interspersed series (48.2%) of flake removals that regularly extend up to the proximal or distal end of the fragments (Fig. 8).

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The production of expedient bone tools at Lingjing provides a new outlook on the prehistoric lifeways of the human groups who visited the site. The presence of a water spring in a grassland-dominated environment with a mosaic of scattered, mixed forests surely attracted both animals and humans, and provided these individuals with a reliable hunting spot at the beginning of the Late Pleistocene. When undertaking a hunting trip, these hunters could anticipate their needs at the hunting grounds and collect a few quartz and quartzite pebbles along the way in the riverbeds located in the vicinity of the site to complement the few tools made of allochthonous material they had in their possession. Following a successful kill, lithic tool manufacture and butchery activities appear to have been undertaken at the site. Although some steps of the operational sequence guiding the production of expedient bone tools are still missing, it appears the Lingjing visitors targeted thick, elongated diaphyseal fragments to modify their edges by direct percussion. The fractures present on these tools indicate bone fragments were knapped while still being fresh. A thorough survey of the location of impact scars on medium-sized mammalian long bones could help us determine whether or not a particular fracturing method was implemented in order to access the marrow while producing elongated diaphyseal fragments. The predominance of flake removal scars on lateral edges, sometime extending all the way to the proximal or distal end of the fragment, implies a modification oriented towards the production of a long, sharp edge. Comparing the size of these fragments with that of unretouched lithic flakes and lithic tools from the same layer reveals an interesting pattern (Fig. 9). Such comparison suggests these bone fragments may have been specifically targeted by the humans visiting Lingjing to complement the small size of the lithics composing their toolkit. The function of the bone tools is a topic to be explored. However, considering that processing carcasses of large and medium size prey has certainly been one of the functions the site has fulfilled, it is likely that these expedient tools were used in butchery or hide processing activities. An experimental and use wear program is currently being implemented to test this hypothesis.

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Our results have implications on our understanding of human behavioural variability during the Middle to Late Pleistocene transition in China. Research undertaken at Lingjing shows the importance of bone as a raw material in the technological system of the human groups that visited the site during this period. Bone tools were use in a variety of stone knapping activities (Doyon et al., 2018, 2019), as implements fit to knap bones to allow marrow extraction (van Kolfschoten et al., 2020), and as a mean to permanently record information in the form of engraved patterns (Z. Li et al., 2019). When adding the evidence from the present study, it appears clearly that the visitors at Lingjing not only understood the mechanical properties of osseous raw material but, most importantly, knew how to take advantage of them in a variety of subsistence, and perhaps symbolic, activities. The diversity of functions for which bone tools were used is also compelling. It reinforces the view that the technological system at Lingjing likely represents an expression of a long-lasting tradition whose origin and development remain to be established (Doyon et al., 2019). On the other hand, the Lingjing case further highlights the inability of lithic technology to adequately describe the whole breath of behavioural variability for the humanities that preceded us. Careful consideration of the faunal assemblages, both from a taphonomic and a technological perspective, especially in East Asia, now allow us to perceive a level of technological complexity that is entirely comparable to penecontemporaneous evidence from other regions of the Old World (Wei et al., 2016; Zhang et al., 2016, 2018; Pitarch Martí et al., 2017; Y. Wei et al., 2017; d'Errico et al., 2018; Z. Li et al., 2019; Li et al., 2020).We can only hope the recent discoveries from Lingjing and other sites will encourage a careful re-examination of faunal assemblages from these perspectives to further our understanding of the cultural trajectories of the technological systems before and after the dispersal of our species in the region.

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Competing interests

The authors have declared that no competing interests exist. LD is a member of the PCI Archaeology Managing Board. LD and Fd'E are two of the PCI Archaeology recommenders.

Author contributions

Conceptualization: LD, Fd'E
Data curation: LZ, LD
Excavations: LZ
Formal analysis: LD, LG Fd'E
Funding acquisition: LZ, LD, Fd'E
Investigation: LD, LZ, LG, WH, Fd'E
Methodology: LD, Fd'E
Project administration: LZ
Software: LD
Supervision: LZ, FdE
Validation: LD
Writing – original draft: LD, Fd'E
Writing – review and editing: LD, LZ, LG, WH, Fd'E

Reference

Anzidei, A.P., 2001. Tools from elephant bones at La Polledrara di Cecanibbio and Rebibbia-Casal de' Pazzi. In: La terra degli elefanti : Atti sel 1° Congresso internazionale. Consiglio Nazionale delle Ricerche, Rome, pp. 415–418.

Anzidei, A.P., Biddittu, I., Mussi, M., Piperno, M., 2001. Lithic and bone industries of OIS 9 and OIS 7 in the Roman area. In: La terra degli elefanti : Atti sel 1° Congresso internazionale. Consiglio Nazionale delle Ricerche, Rome, pp. 3–9.

Ardèvol, J.R., López, R.B., 2009. Home sharing: carnivores in anthropogenic assemblages of the Middle Pleistocene. Journal of taphonomy. 7, 305–324.

Armstrong, A., 2016. Eagles, owls, and coyotes (oh my!): Taphonomic analysis of rabbits and guinea pigs fed to captive raptors and coyotes. Journal of Archaeological Science: Reports. 5, 135–155.

Backwell, L.R., d'Errico, F., 2001. Evidence of termite foraging by Swartkrans early hominids. Proceedings of the National Academy of Sciences. 98, 1358–1363.

Backwell, L.R., d'Errico, F., 2004. The first use of bone tools: a reappraisal of the evidence from Olduvai Gorge, Tanzania. Palaeontologia Africana. 40, 95–158.

Backwell, L.R., d'Errico, F., 2008. Early hominid bone tools from Drimolen, South Africa. Journal of Archaeological Science. 35, 2880–2894.

Baumann, M., Plisson, H., Rendu, W., Maury, S., Kolobova, K., Krivoshapkin, A., 2020. The Neandertal bone industry at Chagyrskaya cave, Altai Region, Russia. Quaternary International.

Behrensmeyer, A.K., 1978. Taphonomic and ecologic information from bone weathering. Paleobiology. 4, 150–162.

Behrensmeyer, A.K., Gordon, K.D., Yanagi, G.T., 1986. Trampling as a cause of bone surface damage and pseudo-cutmarks. Nature. 319, 768–771.

Benson, P.C., Plug, I., Dobbs, J.C., 2004. An analysis of bones and other materials collected by Cape Vultures at the Kransberg and Blouberg colonies, Limpopo Province, South Africa. Ostrich. 75, 118–132.

Binford, L.R., 1981. Bones: Ancient Men and Modern Myths. Academic Press, London.

Blasco, R., Rosell, J., Fernández Peris, J., Cáceres, I., Vergès, J.M., 2008. A new element of trampling: An experimental application on the Leve XII faunal record of Bolomor Cave (Valencia, Spain). Journal of Archaeological Science. 35, 1605–1618.

Blasco, R., Rosell, J., Cuartero, F., Fernández Peris, J., Gopher, A., Barkai, R., 2013. Using bones to shape stones: MIS 9 Bone retouchers at both edges of the Mediterranean Sea. PLoS ONE. 8, e76780.

Blasco, R., Domínguez-Rodrigo, M., Arilla, M., Camarós, E., Rosell, J., 2014. Breaking bones to obtain marrow: A comparative study between percussion by batting bone on an anvil and hammerstone percussion. Archaeometry. 56, 1085–1104.

Blumenschine, R.J., Pobiner, B.L., 2007. Zooarchaeology and the ecology of Oldowan hominin carnivory. In: Ungar, P.S. (Ed.), Evolution of the Human Diet: The Known, the Unknown, and the Unknowable. Oxford University Press, Oxford, pp. 167–190.

Bonhof, W.J., van Kolfschoten, T., 2021. The metapodial hammers from the Lower Palaeolithic site of Schöningen 13 II-4 (Germany): The results of experimental research. Journal of Archaeological Science: Reports. 35, 102685.

Boschian, G., Saccà, D., 2015. In the elephant, everything is good: Carcass use and re-use at Castel di Guido (Italy). Quaternary International. 361, 288–296.

Bourdillat, V., 2014. Repaires de carnivores. In: Denys, C., Patou-Mathis, M. (Eds.), Manuel de taphonomie. Éditions Errance, Arles, pp. 65–100.

Brain, C.K., 1967. Bone weathering and the problem of bone pseudo-tools. Scientific Papers of the Namib Desert Research Station. 1967, 97–99.

Deleted: Anzidei, A.P., Bulgarelli, G.M., Catalano, P., Cerilli, E., Gallotti, R., Lemorini, C., Milli, S., Palombo, M.R., Pantano, W., Santucci, E., 2012. Ongoing research at the late Middle Pleistocene site of La Polledrara di Cecanibbio (central Italy), with emphasis on human–elephant relationships. Quaternary International. 255, 171–187.¶

Formatted: Italian

Brain, C.K., 1981. The Hunters or the Hunted?: An Introduction to African Cave Taphonomy. University of Chicago Press, Chicago.

Bunn, H.T., 1981. Archaeological evidence for meat-eating by Plio-Pleistocene hominids from Koobi Fora and Olduvai Gorge. Nature. 291, 574–577.

Burke, A., d'Errico, F., 2008. A Middle Palaeolithic bone tool from Crimea (Ukraine). Antiquity. 82, 843–852.

Cáceres, I., Esteban-Nadal, M., Bennàsar, M., Fernández-Jalvo, Y., 2011. Was it the deer or the fox? Journal of Archaeological Science. 38, 2767–2774.

Capaldo, S.D., 1998. Methods, marks, and models for inferring hominid and carnivore behavior. Journal of Human Evolution. 35, 317–320.

Chen, C., 1983. Preliminary exploration of the typology and technology of microcore in China - also of the culture relationship between Northeast Aria and Northwestern North America. Acta Anthropologica Sinica. 2, 331–346.

Chia, L.P., Wei, Q., Li, C.R., 1976. Report on the excavation of Hsuchiayao Man site in 1976. Vertebrata PalAsiatica. 17, 277–293.

Christensen, M., Goutas, N. (Eds.), 2018. " À coup d'éclats ! " La fracturation des matières osseuses en Préhistoire. Actes de la séance de la Société préhistorique française, Paris, 25 avril 2017. Société préhistorique française, Paris.

Costamagno, S., Théry-Parisot, I., Kuntz, D., Bon, F., Mensan, R., 2010. Taphonomic impact of prolonged combustion on bones used as fuel. P@lethnologie. 2, 169–183.

Costamagno, S., Bourguignon, L., Soulier, M.-C., Meignen, L., Beauval, C., Rendu, W., Mussini, C., Mann, A., Maureille, B., 2018. Bone retouchers and site function in the Quina Mousterian: The case of Les Pradelles (Marillac-le-Franc, France). In: Hutson, J.M., García-Moreno, A., Noack, E.S., Turner, E., Villaluenga, A., Gaudzinski-Windheuser, S. (Eds.), The Origins of Bone Tool Technologies. Römisch Germanisches ZentralMuseum, Mainz, pp. 165–195.

d'Errico, F., Backwell, L.R., 2009. Assessing the function of early hominin bone tools. Journal of Archaeological Science. 36, 1764–1773.

d'Errico, F., Backwell, L. R., Wadley, L., 2012. Identifying regional variability in Middle Stone Age bone technology: the case of Sibudu Cave. Journal of Archaeological Science. 39, 2479-2495.

d'Errico, F., Doyon, L., Zhang, S., Baumann, M., Lázničková-Galetová, M., Gao, X., Chen, F., Zhang, Y., 2018. The origin and evolution of sewing technologies in Eurasia and North America. Journal of Human Evolution. 125, 71–86.

Dart, R., 1957. The Osteodontokeratic Culture of *Australopithecus Prometheus*. Transvaal Museum, Pretoria.

Daujeard, C., 2007. Exploitation intensive des carcasses de Cerf dans le gisement paléolithique moyen de la grotte de Saint-Marcel (Ardèche). In: Un siècle de construction du discours scientifique en Préhistoire. Actes du Congrès du centenaire de la Société Préhistorique Française, Avignon-Bonnieux, 20-25 septembre 2004. Volume III. Société préhistorique de France, Paris, pp. 481–497.

Daujeard, C., Moncel, M.-H., Fiore, I., Tagliacozzo, A., Bindon, P., Raynal, J.-P., 2014. Middle Paleolithic bone retouchers in Southeastern France: Variability and functionality. Quaternary International. 326–327, 492–518.

Daujeard, C., Valensi, P., Fiore, I., Moigne, A.-M., Tagliacozzo, A., Moncel, M.-H., Santagata, C., Cauche, D., Raynal, J.-P., 2018. A reappraisal of Lower to Middle Palaeolithic bone retouchers from Southeastern France (MIS 11 to 3). In: Hutson, J.M., Noack, E.S., Turner, E., Villaluenga, A., Gaudzinski-Windheuser, S. (Eds.), The Origins of Bone Tool Technologies. Römisch Germanisches ZentralMuseum, Mainz, pp. 93–132.

Formatted: English (US)

de la Peña, P., Wadley, L., Lombard, M., 2013. Quartz bifacial points in the Howiesons Poort of Sibudu. The South African Archaeological Bulletin. 68, 119–136.

Di Buduo, G.M., Costantini, L., Fiore, I., Marra, F., Palladino, D.M., Petronio, C., Rolfo, M.F., Salari, L., Ceruleo, P., Florindo, F., Gaeta, M., Gatta, M., Modesti, V., Pandolfi, L., Sottili, G., 2020. The Bucobello 322 ka-fossil-bearing volcaniclastic-flow deposit in the eastern Vulsini Volcanic District (central Italy): Mechanism of emplacement and insights on human activity during MIS 9. Quaternary International.554, 75–89.

Domínguez-Rodrigo, M., Rayne Pickering, T., Semaw, S., Rogers, M.J., 2005. Cutmarked bones from Pliocene archaeological sites at Gona, Afar, Ethiopia: Implications for the function of the world's oldest stone tools. Journal of Human Evolution. 48, 109–121.

Dong, W., Li, Z., 2009. New Cervids (Artiodactyla, Mammalia) from the Late Pleistocene of Lingjing Site in Henan Province, China. Acta Anthropologica Sinica. 28, 319–326.

Doyon, L., Li, Z., Li, H., d'Errico, F., 2018. Discovery of *circa* 115,000-year-old bone retouchers at Lingjing, Henan, China. PLOS ONE. 13, e0194318.

Doyon, L., Li, H., Li, Z., Wang, H., Zhao, Q., 2019. Further evidence of organic soft hammer percussion and pressure retouch from Lingjing (Xuchang, Henan, China). Lithic Technology. 44, 100–117.

ETTOS, 1985. Techniques de percussion appliquées au matériau osseux, premières expériences. Cahiers de l'Euphrate. 4, 373–81.

Fernández-Jalvo, Y., Andrews, P., 2016. Atlas of Taphonomic Identifications. Springer, Dordrecht.

Fisher Jr, J.W., 1995. Bone surface modifications in zooarchaeology. Journal of Archaeological Method and Theory. 2, 7–68.

Fourvel, J.-B., 2017. Accumulations par les prédateurs non humains. In: Brugal, J.-P. (Ed.), TaphonomieS. Éditions des archives contemporaines, Paris, pp. 389–411.

Galán, A.B., Rodríguez, M., de Juana, S., Domínguez-Rodrigo, M., 2009. A new experimental study on percussion marks and notches and their bearing on the interpretation of hammerstone-broken faunal assemblages. Journal of Archaeological Science. 36, 776–784.

Garnavos, C., Kanakaris, N.K., Lasanianos, N.G., Tzortzi, P., West, R.M., 2012. New classification system for long-bone fractures supplementing the AO/OTA classification. Orthopedics. 35, e709–719.

Gifford-Gonzalez, D., 1991. Bones are not enough: Analogues, knowledge, and interpretive strategies in zooarchaeology. Journal of Anthropological Archaeology. 10, 215–254.

Goren-Inbar, N., 2011. Behavioral and cultural origins of Neanderthals: A Levantine perspective. In: Condemi, S., Weniger, G.-C. (Eds.), Continuity and Discontinuity in the Peopling of Europe. Springer, Dordrecht, pp. 89–100.

Goutas, N., Christensen, M., 2018. Extraction, partitioning, reduction or fracturing? What exactly are we talking about? Discussion of the production of elongated blanks (rod, rod-shaped flakes vs flakes). In: Christensen, M., Goutas, N. (Eds.), "À coup d'éclats!" La fracturation des matières osseuses en Préhistoire : Discussion autour d'une modalité d'exploitation en apparence simple et pourtant mal connue. Actes de La séance de la Société préhistorique française de Paris (25 Avril 2017). Société préhistorique française, Paris, France, pp. 55–76.

Grunwald, A.M., 2016. Analysis of fracture patterns from experimentally marrow-cracked frozen and thawed cattle bones. Journal of Archaeological Science: Reports. 8, 356–365.

Hardy, M., Pothier Bouchard, G., Doyon, L., 2014. Un outil en os à usages multiples dans un contexte moustérien. Bulletin de la Société préhistorique française. 111, 741–744.

Formatted: French

Harmand, S., Lewis, J.E., Feibel, C.S., Lepre, C.J., Prat, S., Lenoble, A., Boës, X., Quinn, R.L., Brenet, M., Arroyo, A., Taylor, N., Clément, S., Daver, G., Brugal, J.-P., Leakey, L., Mortlock, R.A., Wright, J.D., Lokorodi, S., Kirwa, C., Kent, D.V., Roche, H., 2015. 3.3-million-year-old stone tools from Lomekwi 3, West Turkana, Kenya. Nature. 521, 310–315.

Haynes, G., 1983. A guide for differentiating mammalian carnivore taxa responsible for gnaw damage to herbivore limb bones. Paleobiology. 9, 164–172.

Haynes, G., 1991. Mammoths, Mastodonts, and Elephants: Biology, Behavior and the Fossil Record. Cambridge University Press, Cambridge.

Henri-Martin, Dr., 1910. La percussion osseuse et les esquilles qui en dérivent. Expérimentation. Bulletin de la Société préhistorique de France. 7, 299–304.

Hockett, B.S., 1996. Corroded, thinned and polished bones created by Golden Eagles (*Aquila chrysaetos*): Taphonomic implications for archaeological interpretations. Journal of Archaeological Science. 23, 587–591.

Hutson, J.M., Burke, C.C., Haynes, G., 2013. Osteophagia and bone modifications by giraffe and other large ungulates. Journal of Archaeological Science. 40, 4139–4149.

Hutson, J.M., García-Moreno, A., Noack, E.S., Turner, E., Villaluenga, A., Gaudzinski-Windheuser, S. (Eds.), 2018a. The Origins of Bone Tool Technologies. Römisch Germanisches ZentralMuseum, Mainz.

Hutson, J.M., Villaluenga, A., García-Moreno, A., Turner, E., Gaudzinski-Windheuser, S., 2018b. On the use of metapodials as tools at Schöningen 13II-4. In: Hutson, J.M., García-Moreno, A., Noack, E.S., Turner, E., Villaluenga, A., Gaudzinski-Windheuser, S. (Eds.), The Origins of Bone Tool Technologies. Römisch Germanisches ZentralMuseum, Mainz, pp. 53–91.

Ingold, T., 2002. The Perception of the Environment: Essays on Livelihood, Dwelling and Skill. Routledge, London.

Joordens, J.C.A., d'Errico, F., Wesselingh, F.P., Munro, S., de Vos, J., Wallinga, J., Ankjærgaard, C., Reimann, T., Wijbrans, J.R., Kuiper, K.F., Mücher, H.J., Coqueugniot, H., Prié, V., Joosten, I., van Os, B., Schulp, A.S., Panuel, M., van der Haas, V., Lustenhouwer, W., Reijmer, J.J.G., Roebroeks, W., 2015. *Homo erectus* at Trinil on Java used shells for tool production and engraving. Nature. 518, 228–231.

Julien, M.-A., Hardy, B., Stahlschmidt, M.C., Urban, B., Serangeli, J., Conard, N.J., 2015. Characterizing the Lower Paleolithic bone industry from Schöningen 12 II: A multi-proxy study. Journal of Human Evolution. 89, 264–286.

Klein, R.G., 2009. The Human Career (3rd ed.). University of Chicago Press, Chicago.

Kozlikin, M.B., Rendu, W., Plisson, H., Baumann, M., Shunkov, M.V., 2020. Unshaped bone tools from Denisova Cave, Altai. Archaeology, Ethnology & Anthropology of Eurasia. 48, 16–28.

Kretzoi, M., Dobosi, V.T., 1990. Vértesszőlős: Site, Man and Culture. Akadémiai Kiadó, Budapest.

Kuhn, S.L., 2020. The Evolution of Paleolithic Technologies. Routledge, London.

Lemorini, C., Plummer, T.W., Braun, D.R., Crittenden, A.N., Ditchfield, P.W., Bishop, L.C., Hertel, F., Oliver, J.S., Marlowe, F.W., Schoeninger, M.J., Potts, R., 2014. Old stones' song: Use-wear experiments and analysis of the Oldowan quartz and quartzite assemblage from Kanjera South (Kenya). Journal of Human Evolution. 72, 10–25.

Lemorini, C., Bishop, L.C., Plummer, T.W., Braun, D.R., Ditchfield, P.W., Oliver, J.S., 2019. Old stones' song—second verse: Use-wear analysis of rhyolite and fenetized andesite artifacts from the Oldowan lithic industry of Kanjera South, Kenya. Archaeological and Anthropological Sciences. 11, 4729–4754.

Lewis, J.E., Harmand, S., 2016. An earlier origin for stone tool making: Implications for cognitive evolution and the transition to Homo. Philosophical Transactions of the Royal Society B: Biological Sciences. 371, 20150233.

Li, H., Li, Z., Lotter, M.G., Kuman, K., 2018. Formation processes at the early Late Pleistocene archaic human site of Lingjing, China. Journal of Archaeological Science. 96, 73–84.

Li, H., Li, Z., Gao, X., Kuman, K., Sumner, A., 2019. Technological behavior of the early Late Pleistocene archaic humans at Lingjing (Xuchang, China). Archaeological and Anthropological Sciences. 11, 3477–3490.

Li, Z., Dong, W., 2007. Mammalian fauna from the Lingjing Paleolithic site in Xuchang, Henan Province. Acta Anthropologica Sinica. 26, 345–360.

Li, Z., Ma, H., 2016. Techno-typological analysis of the microlithic assemblage at the Xuchang Man site, Lingjing, central China. Quaternary International. 400, 120–129.

Li, Z., Shen, C., 2010. Use-wear analysis confirms the use of Palaeolithic bone tools by the Lingjing Xuchang early human. Chinese Science Bulletin. 55, 2282–2289.

Li, Z., Shen, C., 2011. Excavation report of the Lingjing Paleolithic Site in 2006. Chinese Archaeology. 11, 65–73.

Li, Z., Li, Y., Kato, S., 2014. Observations on microblade core technologies from lever 5 of the Xuchang Man site, Lingjing. Acta Anthropologica Sinica. 33, 285–303.

Li, Z., Kunikita, D., Kato, S., 2017a. Early pottery from the Lingjing site and the emergence of pottery in northern China. Quaternary International. 441, 49–61.

Li, Z., Wu, X., Zhou, L., Liu, W., Gao, X., Nian, X., Trinkaus, E., 2017b. Late Pleistocene archaic human crania from Xuchang, China. Science. 355, 969–972.

Li, Z., Xing, Y., Mu, J., Wu, X., Li, Y., Kato, S., 2018. Report of the excavation of microlithic implements on the 5th layer of Lingjing, Xuchang Man site from 2008 to 2013. Huaxia Kaogu / Huaxia Archaeology. 2018, 3–33.

Li, Z., Doyon, L., Li, H., Wang, Q., Zhang, Z., Zhao, Q., d'Errico, F., 2019. Engraved bones from the archaic hominin site of Lingjing, Henan Province. Antiquity. 93, 886–900.

Li, Z., Doyon, L., Fang, H., Ledevin, R., Queffelec, A., Raguin, E., d'Errico, F., 2020. A Paleolithic bird figurine from the Lingjing site, Henan, China. PLOS ONE. 15, e0233370.

Lloveras, L., Nadal, J., Moreno-García, M., Thomas, R., Anglada, J., Baucells, J., Martorell, C., Vilasís, D., 2014. The role of the Egyptian Vulture (*Neophron percnopterus*) as a bone accumulator in cliff rock shelters: An analysis of modern bone nest assemblages from North-eastern Iberia. Journal of Archaeological Science. 44, 76–90.

Lyman, R.L., 1984. Broken Bones, Bone expediency tools, and bone pseudotools: Lessons from the blast zone around Mount St. Helens, Washington. American Antiquity. 49, 315–333.

Lyman, R.L., 1994. Vertebrate Taphonomy. Cambridge University Press, New York.

Madgwick, R., 2014. What makes bones shiny? Investigating trampling as a cause of bone abrasion. Archaeological and Anthropological Sciences. 6, 163–173.

Madrigal, T.C., Blumenschine, R.J., 2000. Preferential processing of high return rate marrow bones by Oldowan hominids: A comment on Lupo. Journal of Archaeological Science. 27, 739–741.

Mallye, J.-B., Thiébaut, C., Mourre, V., Costamagno, S., Claud, É., Weisbecker, P., 2012. The Mousterian bone retouchers of Noisetier Cave: Experimentation and identification of marks. Journal of Archaeological Science. 39, 1131–1142.

Mania, D., Mania, U., 2003. Bilzingsleben - *Homo erectus*, his culture and his environment. The most important results of research. In: Burdukiewicz, J.M., Ronen, A. (Eds.), Lower Palaeolithic Small Tools in Europe and the Levant. British Archaeological Reports, Oxford, England, pp. 29–48.

Margalida, A., 2008. Presence of bone remains in the ossuaries of Bearded Vultures (*Gypaetus Barbatus*): Storage or nutritive rejection. The Auk. 125, 560–564.

Marín Arroyo, A.B., Fosse, P., Vigne, J.-D., 2009. Probable evidences of bone accumulation by Pleistocene bearded vulture at the archaeological site of El Mirón Cave (Spain). Journal of Archaeological Science. 36, 284–296.

Marom, N., 2016. Fragmentation in zooarchaeological assemblages: The role of equifinal, random processes. Journal of Archaeological Science: Reports. 8, 11–14.

Martinón-Torres, M., Wu, X., Bermúdez de Castro, J.M., Xing, S., Liu, W., 2017. *Homo sapiens* in the Eastern Asian Late Pleistocene. Current Anthropology. 58, S434–S448.

Mateo-Lomba, P., Fernándes-Marchena, J.L., Ollé, A., Cáceres, I., 2020. Knapped bones used as tools: Experimental approach on different activities. Quaternary International. 569-570, 51–65.

Miller-Antonio, S., Scherpartz, L.A., Bakken, D., 2000. Raw material selection and evidence for rhinoceros tooth tools at Dadong Cave, southern China. Antiquity. 74, 372–379.

Moigne, A.-M., Valensi, P., Auguste, P., García-Solano, J., Tuffreau, A., Lamotte, A., Barroso, C., Moncel, M.-H., 2016. Bone retouchers from Lower Palaeolithic sites: Terra Amata, Orgnac 3, Cagny-l'Epinette and Cueva del Angel. Quaternary International. 409, 195–212.

Moncel, M.-H., Moigne, A.-M., Combier, J., 2012. Towards the Middle Palaeolithic in Western Europe: The case of Orgnac 3 (southeastern France). Journal of Human Evolution. 63, 653–666.

Morin, E., 2010. Taphonomic implications of the use of bone as fuel. P@lethnologie. 2, 209–217.

Morin, E., 2020. Revisiting bone grease rendering in highly fragmented assemblages. American Antiquity. 85, 535–553.

Morin, E., Soulier, M.-C., 2017. New criteria for the archaeological identification of bone grease processing. American Antiquity. 82, 96–122.

Morlan, R.E., 1984. Toward the definition of criteria for the recognition of artificial bone alterations 1. Quaternary Research. 22, 160–171.

Mourre, V., Villa, P., Henshilwood, C.S., 2010. Early use of pressure flaking on lithic artifacts at Blombos Cave, South Africa. Science. 330, 659–662.

Mozota Holgueras, M., 2012. El hueso como material prima: El utillage óseo del final del Musteriense en el sector central del norte de la Península Ibérica (Ph.D.). Universidad de Cantabria, Santander.

Myers, T.P., Voorhies, M.R., Corner, R.G., 1980. Spiral fractures and bone pseudotools at paleontological sites. American Antiquity. 45, 483–490.

Naldini, E.S., Muttoni, G., Parenti, F., Scardia, G., Segre, A.G., 2009. Nouvelles recherches dans le bassin Plio-Pléistocène d'Anagni (Latium méridional, Italie). L'Anthropologie. 113, 66–77.

Nian, X.M., Zhou, L.P., Qin, J.T., 2009. Comparisons of equivalent dose values obtained with different protocols using a lacustrine sediment sample from Xuchang, China. Radiation Measurements. 44, 512–516.

Njau, J.K., Blumenschine, R.J., 2006. A diagnosis of crocodile feeding traces on larger mammal bone, with fossil examples from the Plio-Pleistocene Olduvai Basin, Tanzania. Journal of Human Evolution. 50, 142–162.

Njau, J.K., Blumenschine, R.J., 2012. Crocodylian and mammalian carnivore feeding traces on hominid fossils from FLK 22 and FLK NN 3, Plio-Pleistocene, Olduvai Gorge, Tanzania. Journal of Human Evolution. 63, 408–417.

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Noe-Nygaard, N., 1987. Taphonomy in archaeology with special emphasis on man as a biasing factor. Journal of Danish Archaeology. 6, 7–62.

Noe-Nygaard, N., 1989. Man-made trace fossils on bones. Human Evolution. 4, 461–491.

Outram, A.K., 2001. A new approach to identifying bone marrow and grease exploitation: Why the “indeterminate” fragments should not be ignored. Journal of Archaeological Science. 28, 401–410.

Pante, M., Torre, I. de la, d’Errico, F., Njau, J., Blumenschine, R., 2020. Bone tools from Beds II–IV, Olduvai Gorge, Tanzania, and implications for the origins and evolution of bone technology. Journal of Human Evolution. 148, 102885.

Patou-Mathis, M. (Ed.), 1994. Outillage peu élaboré en os et bois de cervidés IV. Éditions du CEDARC, Treignes, Belgique.

Pei, W.C., 1939. The Upper Cave Industry of Choukoutien. Geological Survey of China, Beijing.

Pérez, L., Hernández, C.M., Galván, B., 2019. Bone retouchers from the Middle Palaeolithic site of El Salt, Stratigraphic Unit Xa (Alicante, Spain): First data and comparison with the Middle to Upper Pleistocene European record. International Journal of Osteoarchaeology. 29, 238–252.

Pérez Ripoll, M., 1992. Mascas de carnicería, fracturas intencionadas y mordeduras de carnívoros en huesos prehistóricos del Mediterráneo español. Instituto de cultura “Juan Gil-Albert,” Alicante.

Pickering, T.R., Egeland, C.P., 2006. Experimental patterns of hammerstone percussion damage on bones: implications for inferences of carcass processing by humans. Journal of Archaeological Science. 33, 459–469.

Pitarch Martí, A., Wei, Y., Gao, X., Chen, F., d’Errico, F., 2017. The earliest evidence of coloured ornaments in China: The ochred ostrich eggshell beads from Shuidonggou Locality 2. Journal of Anthropological Archaeology. 48, 102–113.

R Development Core Team, 2008. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna.

Rabinovich, R., Ackermann, O., Aladjem, E., Barkai, R., Biton, R., Milevski, I., Solodenko, N., Marder, O., 2012. Elephants at the Middle Pleistocene Acheulian open-air site of Revadim Quarry, Israel. Quaternary International. 276–277, 183–197.

Reynard, J.P., 2014. Trampling in coastal sites: An experimental study on the effects of shell on bone in coastal sediment. Quaternary International. 330, 156–170.

Romandini, M., Cristiani, E., Peresani, M., 2015. A retouched bone shaft from the Late Mousterian at Fumane Cave (Italy). Technological, experimental and micro-wear analysis. Comptes Rendus Palevol. 14, 63–72.

Rosell, J., Blasco, R., Campeny, G., Díez, J.C., Alcalde, R.A., Menéndez, L., Arsuaga, J.L., Bermúdez de Castro, J.M., Carbonell, E., 2011. Bone as a technological raw material at the Gran Dolina site (Sierra de Atapuerca, Burgos, Spain). Journal of Human Evolution. 61, 125–131.

Sanchis Serra, A., Real Margalef, C., Morales Pérez, J.V., Pérez Ripoll, M., Tormo Cuñat, C., Carrión Marco, Y., Pérez Jordá, G., Ribera Gómez, A., Bolufer Marqués, J., Villaverde Bonilla, V., 2014. Towards the identification of a new taphonomic agent: An analysis of bone accumulations obtained from modern Egyptian vulture (*Neophron percnopterus*) nests. Quaternary International. 330, 136–149.

Sano, K., Beyene, Y., Katoh, S., Koyabu, D., Endo, H., Sasaki, T., Asfaw, B., Suwa, G., 2020. A 1.4-million-year-old bone handaxe from Konso, Ethiopia, shows advanced tool technology in the early Acheulean. Proceedings of the National Academy of Sciences. 117, 18393–18400.

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Formatted: English (CAN)

Santucci, E., Marano, F., Cerilli, E., Fiore, I., Lemorini, C., Palombo, M.R., Anzidei, A.P., Bulgarelli, G.M., 2016. Palaeoloxodon exploitation at the Middle Pleistocene site of La Polledrara di Cecanibbio (Rome, Italy). Quaternary International. 406, 169–182.

Serangeli, J., Böhner, U., Van Kolfschoten, T., Conard, N.J., 2015. Overview and new results from large-scale excavations in Schöningen. Journal of Human Evolution. 89, 27–45.

Shipman, P., Rose, J., 1983. Early hominid hunting, butchering, and carcass-processing behaviors: Approaches to the fossil record. Journal of Anthropological Archaeology. 2, 57–98.

Shipman, P., Rose, P., 1988. Bone tools: An experimental approach. In: Olsen, S.L. (Ed.), Scanning Electron Microscopy in Archaeology. British Archaeological Reports, Oxford, pp. 303–335.

Smith, G.M., 2013. Taphonomic resolution and hominin subsistence behaviour in the Lower Palaeolithic: Differing data scales and interpretive frameworks at Boxgrove and Swanscombe (UK). Journal of Archaeological Science. 40, 3754–3767.

Sohn, P., Park, Y., Han, C., 1991. Yonggul Cave: Palaeontological evidence and cultural behaviour. Bulletin of the Indo-Pacific Prehistory Association. 10, 92–98.

Stammers, R.C., Caruana, M.V., Herries, A.I.R., 2018. The first bone tools from Kromdraai and stone tools from Drimolen, and the place of bone tools in the South African Earlier Stone Age. Quaternary International. 495, 87–101.

Stavrova, T., Borel, A., Daujeard, C., Vettese, D., 2019. A GIS-based approach to long bone breakage patterns derived from marrow extraction. PLOS ONE. 14, e0216733.

Tartar, É., 2012. The recognition of a new type of bone tools in Early Aurignacian assemblages: Implications for understanding the appearance of osseous technology in Europe. Journal of Archaeological Science. 39, 2348–2360.

Trinkaus, E., Wu, X.-J., 2017. External auditory exostoses in the Xuchang and Xujiayao human remains: Patterns and implications among eastern Eurasian Middle and Late Pleistocene crania. PLOS ONE. 12, e0189390.

van Kolfschoten, T., 2014. The Palaeolithic locality Schöningen (Germany): A review of the mammalian record. Quaternary International. 326–327, 469–480.

van Kolfschoten, T., Parfitt, S.A., Serangeli, J., Bello, S.M., 2015. Lower Paleolithic bone tools from the ‘Spear Horizon’ at Schöningen (Germany). Journal of Human Evolution. 89, 226–263.

van Kolfschoten, T., Li, Z., Wang, H., Doyon, L., 2020. The Middle Palaeolithic site of Lingjing (Xuchang, Henan, China): Preliminary new results. Analecta Praehistorica Leidensia. 50, 21–28.

Vercoutère, C., Patou-Mathis, M., Giacobini, G., 2014. Rôle des agents biologiques non humains dans l’origine et l’histoire des assemblages osseux de grands mammifères issus de sites archéologiques pléistocènes : Pseudo-objets. In: Denys, C., Patou-Mathis, M. (Eds.), Manuel de taphonomie. Éditions Errance, Arles, pp. 263–270.

Verna, C., d’Errico, F., 2011. The earliest evidence for the use of human bone as a tool. Journal of Human Evolution. 60, 145–157.

Vettese, D., Blasco, R., Cáceres, I., Gaudzinski-Windheuser, S., Moncel, M.-H., Hohenstein, U.T., Daujeard, C., 2020a. Towards an understanding of hominin marrow extraction strategies: a proposal for a percussion mark terminology. Archaeological and Anthropological Sciences. 12, 48.

Vettese, D., Trajanka, S., Borel, A., Marin, J., Moncel, M.-H., Arzarello, M., Daujead, C., 2020b. A way to break bones? The weight of intuitiveness. OSF Preprints.

Villa, P., Bartram, L., 1996. Flaked bone from a hyena den. Paléo, Revue d’Archéologie Préhistorique. 8, 143–159.

Villa, P., d'Errico, F., 2001. Bone and ivory points in the Lower and Middle Paleolithic of Europe. Journal of Human Evolution. 41, 69–112.

Villa, P., Mahieu, E., 1991. Breakage patterns of human long bones. Journal of Human Evolution. 21, 27–48.

Villa, P., Castel, J.-C., Beauval, C., Bourdillat, V., Goldberg, P., 2004. Human and carnivore sites in the European Middle and Upper Paleolithic: Similarities and differences in bone modification and fragmentation. Revue de Paléobiologie. 23, 705–730.

Vincent, A., 1993. L'outillage osseux au Paléolithique moyen : Une nouvelle approche. Ph.D., Université de Paris X.

Wadley, L., 2020. A camera trap record of scavengers at a kudu carcass: implications for archaeological bone accumulations. Transactions of the Royal Society of South Africa.

Wallace, I.J., Shea, J.J., 2006. Mobility patterns and core technologies in the Middle Paleolithic of the Levant. Journal of Archaeological Science. 33, 1293–1309.

Wang, W., Wu, Y., Song, G., Zhao, K., Li, Z., 2014. Pollen and fungi spore analysis on Hyaenid coprolite from the Xuchang Man Site, Central China. Chinese Science Bulletin. 58, 51–56.

Wang, W., Li, Z., Song, G., Wu, Y., 2015. A study of possible hyaena coprolites from the Lingjing site, Central China. Acta Anthropologica Sinica. 34, 117–125.

Wei, G., He, C., Hu, Y., Yu, K., Chen, S., Pang, L., Wu, Y., Huang, W., Yuan, W., 2017. First discovery of a bone handaxe in China. Quaternary International. 434, 121–128.

Wei, Q., 1985. Paleoliths from the Lower Pleistocene of the Nihewan beds in the Donggutuo site. Acta Anthropologica Sinica. 4, 289-300.

Wei, Y., d'Errico, F., Vanhaeren, M., Li, F., Gao, X., 2016. An early instance of Upper Palaeolithic personal ornamentation from China: The freshwater shell bead from Shuidonggou 2. PLOS ONE. 11, e0155847.

Wei, Y., d'Errico, F., Vanhaeren, M., Peng, F., Chen, F., Gao, X., 2017. A technological and morphological study of Late Paleolithic ostrich eggshell beads from Shuidonggou, North China. Journal of Archaeological Science. 85, 83–104.

Zhang, S., Li, Z., Zhang, Y., Gao, X., 2009. Mortality profiles of the large herbivores from Lingjing Xuchang Man Site, Henan Province and the early emergence of the modern human behaviours in East Asia. Chinese Science Bulletin. 54, 3857–3863.

Zhang, S., Gao, X., Zhang, Y., Li, Z., 2011a. Taphonomic analysis of the Lingjing fauna and the first report of a Middle Paleolithic kill-butchery site in North China. Chinese Science Bulletin. 56, 3213–3219.

Zhang, S., Li, Z., Zhang, Y., Gao, X., 2011b. Cultural modifications on the animal bones from the Lingjing site, Henan Province. Acta Anthropologica Sinica. 30, 313–326.

Zhang, S., Li, Z., Zhang, Y., Gao, X., 2012. Skeletal element distributions of the large herbivores from the Lingjing site, Henan Province, China. Science China : Earth Sciences. 55, 246–253.

Zhang, S., d'Errico, F., Backwell, L.R., Zhang, Y., Chen, F., Gao, X., 2016. Ma'anshan cave and the origin of bone tool technology in China. Journal of Archaeological Science. 65, 57–69.

Zhang, S., Doyon, L., Zhang, Y., Gao, X., Chen, F., Guan, Y., d'Errico, F., 2018. Innovation in bone technology and artefact types in the late Upper Palaeolithic of China: Insights from Shuidonggou Locality 12. Journal of Archaeological Science. 93, 82–93.

Zhao, H., Doyon, L., 2020. A century of archaeological heritage protection and exhibition in China. The Historic Environment: Policy & Practice.

Zhao, Q., Ma, H., Bae, C.J., 2019. New discoveries from the early Late Pleistocene Lingjing site (Xuchang). Quaternary International.

Zhou, G.X., 1974. Stone age remains from Lingjing, Xuchang of Henan province. Kaogu. 2, 91–108.

Legends

Figure legends

Fig. 1 Location of the Lingjing site, and schematic representation of the stratigraphy (from Doyon et al., 2018).

Fig. 2 Location and frequency of the blows produced with a hammerstone during the experimental marrow extraction on *Equus caballus* long bones (for each element, from left to right, anterior, posterior, medial, and lateral aspect). (a-d) Series 1: (a) femur, (b) tibia, (c) humerus, (d) radius. (e-f) Series 2: (e) tibia, (f) humerus. Scale = 10 cm.

Fig. 3 Relative frequencies of faunal fragments from Lingjing, layer 11, per maximum length (mm) size class. Dark green: PBT and RCS combined; Yellow: CCS; Light green: area of overlap between both frequency distributions. Notice the underrepresentation of small faunal remains in the assemblage from the PBT and RCS.

Fig. 4 Frequencies of faunal fragments (in grey) and of specimens bearing flake scars (in blue) per maximum length (mm) size class. (a) PBT; (b) RCS; (c) CCS; (d) experimental Series 1 and Series 2 combined.

Fig. 5 (a) Number, and (b) breath (mm) of flake scars documented on the specimens considered in the present study by location, arrangement and sub-sample. The sample code contains information on: 1) the location of the flake scars: U = unifacial (no distinction between cortical and medullar surfaces), B = bifacial; 2) the sub-sample: PBT = Potential Bone Tools (dark green), RCS = Restricted Control Sample (light green), CCS = Complete Control Sample (yellow), Exp. S1 = Experimental Series 1 (light blue), Exp. S2 = Experimental Series 2 (dark blue); 3) the arrangement of the flake scars on each specimen: iso = isolated, con = contiguous, int = interspersed series. The grey band refers to μ ± 1σ for the minimal and maximal mean values recorded on the experimental sub-samples.

Fig. 6 Sample of diaphyseal fragments bearing flake scars from Lingjing, layer 11, interpreted as expedient osseous tools. Refer to SI Table 1 for data. Scales = 1cm.

Fig. 7 Sample of diaphyseal fragments bearing flake scars from Lingjing, layer 11, interpreted as expedient osseous tools. Refer to SI Table 1 for data. Scales = 1cm.

Fig. 8 Close-up views of a sample of diaphyseal fragments bearing flake scars from Lingjing, layer 11. Dots indicate the location of flake scars produced by direct percussion. Notice the variability in the flaking pattern and distribution. Scales = 1cm.

Fig. 9 Morphometric comparison between the unretouched lithic flakes (green), lithic tools (blue) and expedient osseous tools (red) from Lingjing, layer 11. Data for the lithic remains extracted from Zhao et al., 2019, Fig. 3.

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Table legends

Tab. 1 Proportion of specimens bearing a percussion bulb, relative frequencies of the origin of fragments, flakes, and splinters, and morphometric data of the remains produced during the experimental marrow extraction on *Equus caballus* long bones by experimenter.

Tab. 2 Summary of the morphometric data for the samples considered in the present study and comparison with specimens bearing flake scars by sample.

Tab. 3 Relative proportion for the location and arrangement of flake scars by sample considered in the present study.

Tab. 4 Morphometric data on the compacta thickness and relative frequencies for natural and anthropogenic alterations recorded on the archaeological samples from Lingjing, layer 11, based on the presence or absence of flake scars on the specimens.

SI Table legends

SI Tab. 1 Contextual, taphonomic, and morphometric data for the diaphyseal fragments bearing flake scars from Lingjing, layer 11, interpreted as expedient osseous tools. *Note:* With regards to the breath of flake scars, empty cells were added to signal a discontinuity between two flake scars or series of flake scars. This affects only the specimens on which interspersed series were observed.

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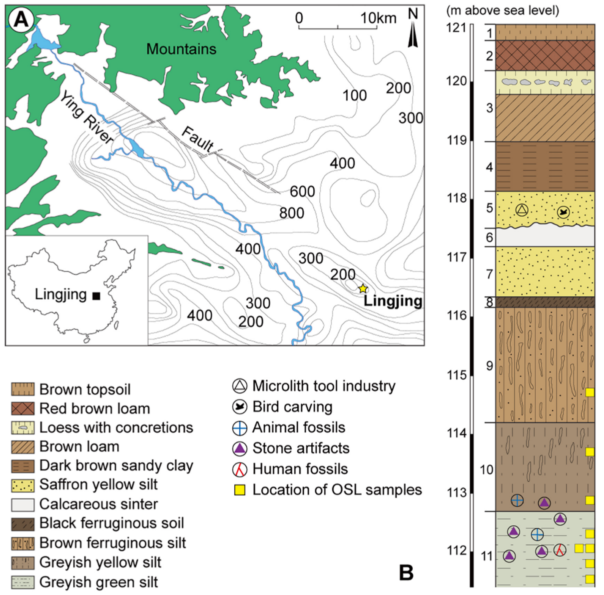

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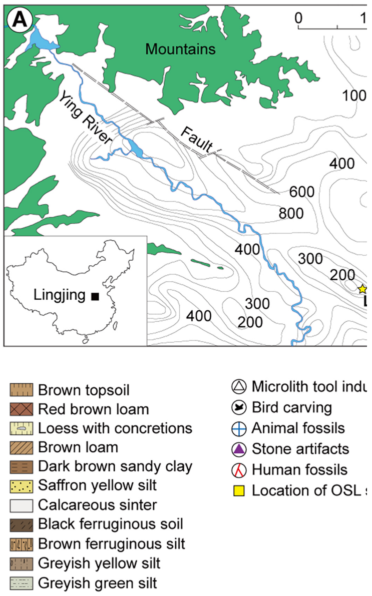

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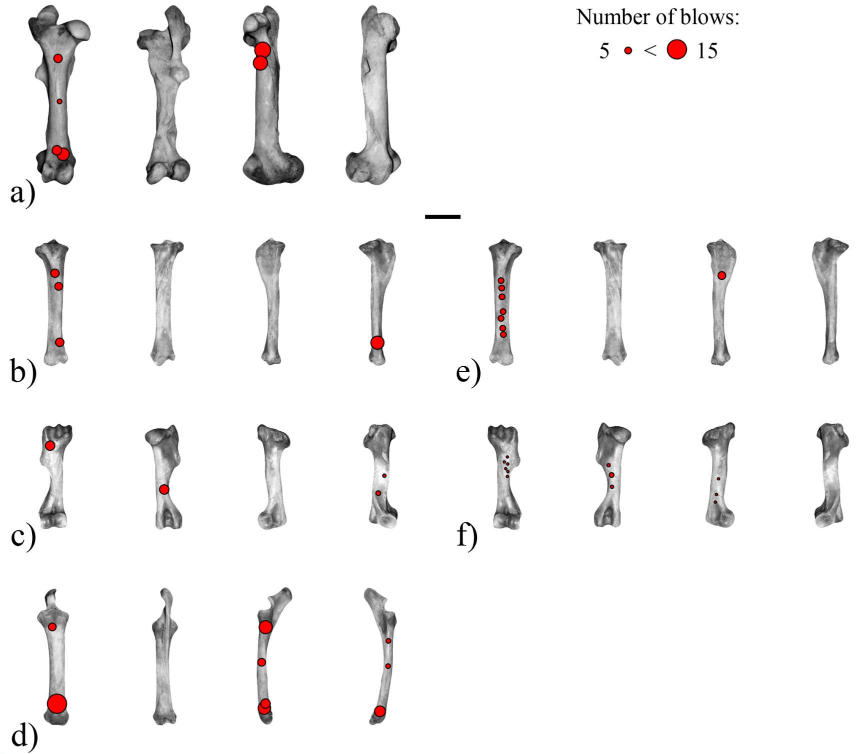

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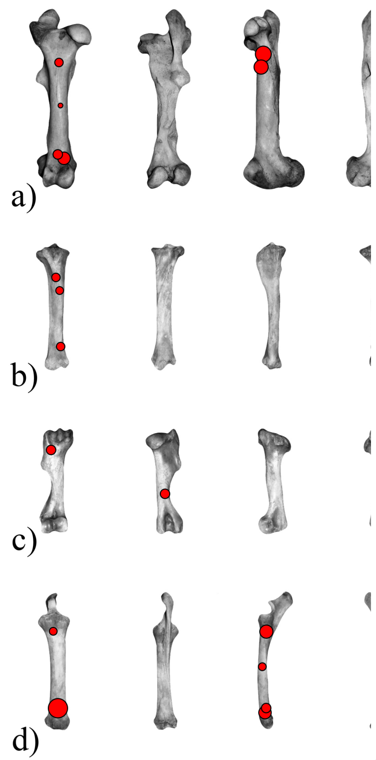

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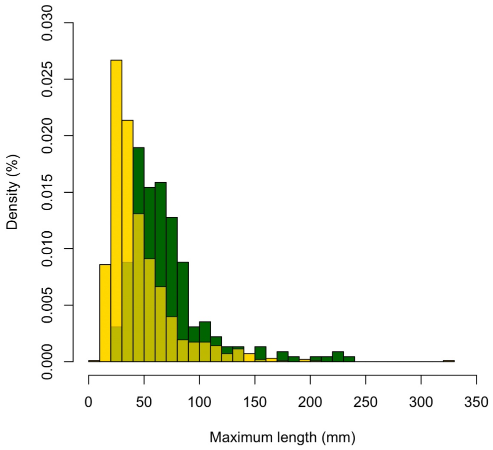

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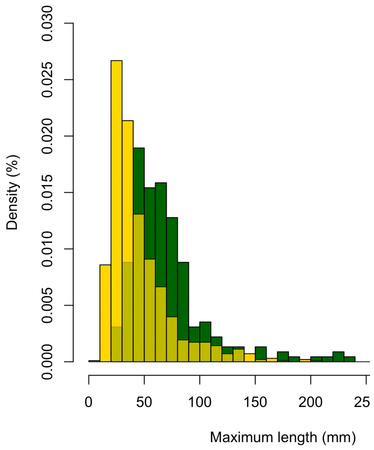

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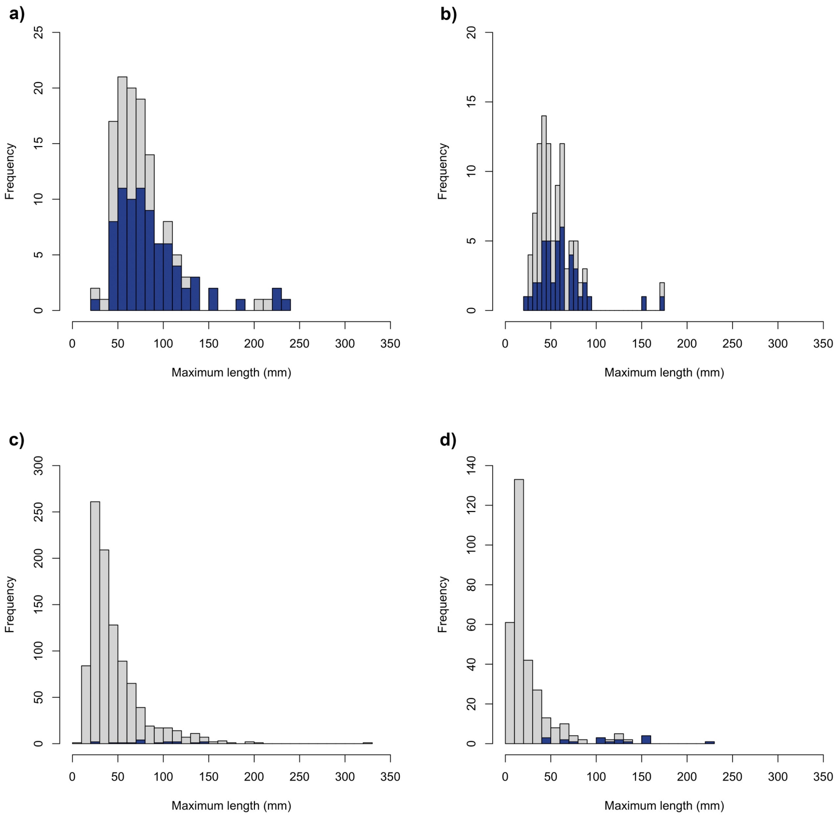

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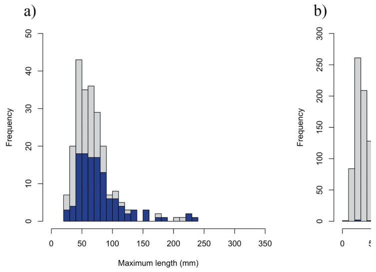

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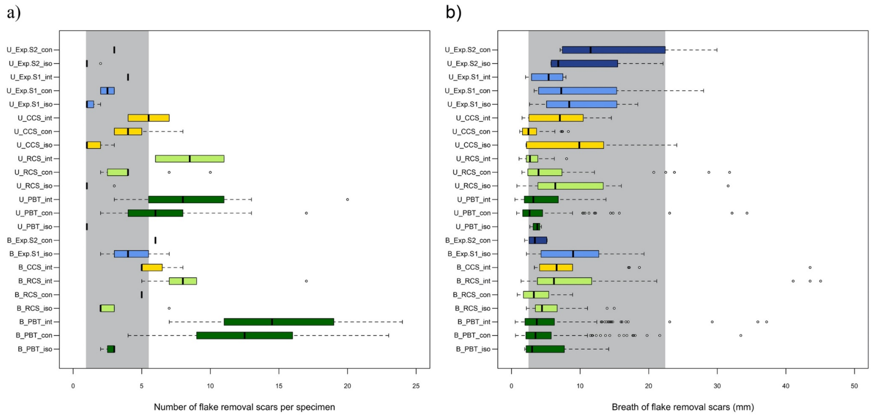

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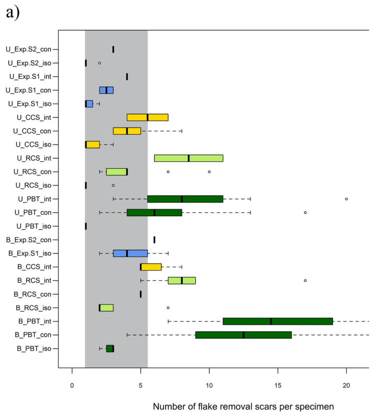

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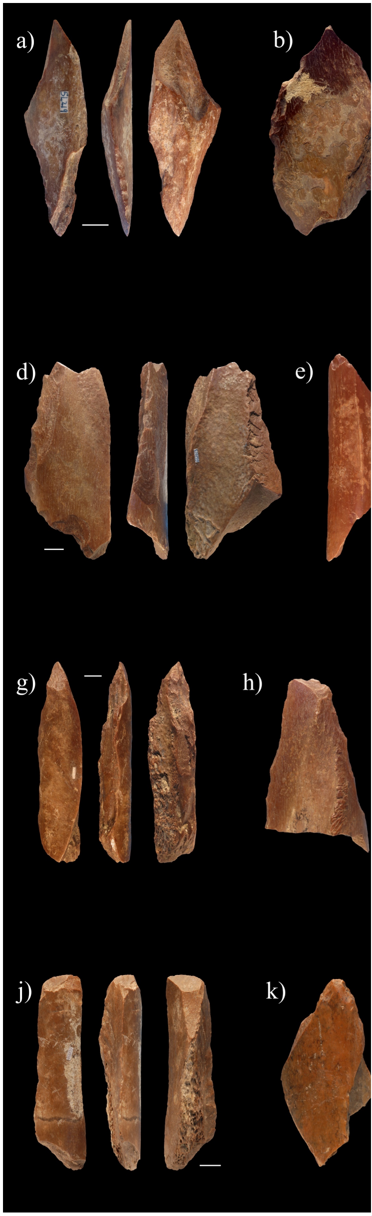

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Fig. 8

Fig. 8 Close-up views of a sample of diaphyseal fragments bearing flake scars from Lingjing, layer 11. Dots indicate the location of flake scars produced by direct percussion. Notice the variability in the flaking pattern and distribution. Scales = 1cm.

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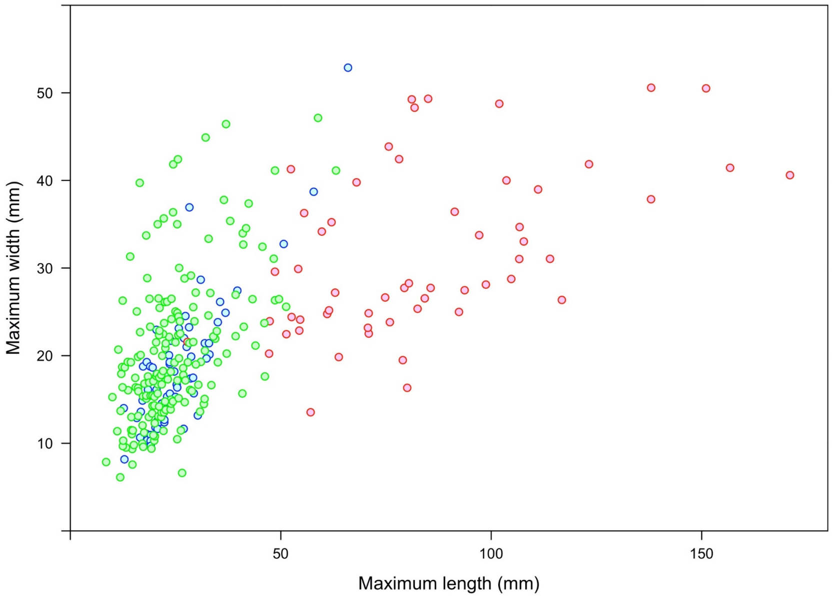

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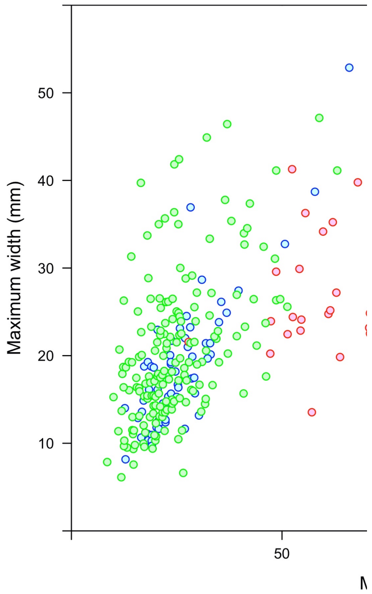

Tab. 1 Proportion of specimens bearing a percussion bulb, relative frequencies of the origin of fragments, flakes, and splinters, and morphometric data of the remains produced during the experimental marrow extraction on *Equus caballus* long bones by experimenter.

Series	Element	Category	*n*	% w/ perc. bulb*	Flakes & Splinters' Origin					Dimensions (in mm)		
					% Cortical	% Medular	% Both	% Unknown		Maximum Length	Maximum Width	Maximum Thickness
1	Humerus	Fragment	3						μ	102.06	33.84	16.79
									σ	45.97	14.01	14.89
		Flake	7	28.57%	42.86%	28.57%	28.57%	0.00%	μ	31.38	13.66	3.98
									σ	12.86	3.07	0.91
		Splinter	18	0.00%	27.78%	16.67%	5.56%	50.00%	μ	11.06	5.58	2.14
									σ	5.95	2.81	1.13
	Radius	Fragment	7						μ	102.15	33.05	17.05
									σ	26.71	9.19	7.34
		Flake	8	25.00%	37.50%	12.50%	50.00%	0.00%	μ	43.25	16.95	9.00
									σ	8.90	6.17	4.29
		Splinter	34	17.65%	29.41%	11.76%	0.00%	58.82%	μ	14.10	5.95	2.22
									σ	5.60	2.90	1.25
	Femur	Fragment	8						μ	97.82	37.99	24.22
									σ	34.38	13.36	14.44
		Flake	3	33.33%	100.00%	0.00%	0.00%	0.00%	μ	21.59	16.90	12.45
									σ	1.26	5.26	7.87
		Splinter	28	0.00%	14.29%	25.00%	10.71%	50.00%	μ	19.09	7.47	3.25
									σ	10.43	2.84	2.26
	Tibia	Fragment	2						μ	190.78	59.48	35.10
									σ	NA	NA	NA
		Flake	3	66.67%	33.33%	33.33%	33.33%	0.00%	μ	56.61	20.14	8.55
									σ	21.17	7.30	2.49
		Splinter	33	12.12%	27.27%	6.06%	9.09%	57.58%	μ	21.81	7.22	2.90
									σ	15.34	3.94	2.07
2	Humerus	Fragment	4						μ	133.30	64.20	42.66
									σ	23.01	10.72	16.98
		Flake	7	42.86%	42.86%	0.00%	42.86%	14.29%	μ	34.01	18.38	5.96
									σ	10.75	4.67	3.24
		Splinter	14	7.14%	14.29%	14.29%	14.29%	57.14%	μ	12.93	7.08	3.19
									σ	4.92	3.21	1.90
	Tibia	Fragment	9						μ	66.04	28.76	15.67
									σ	19.41	8.77	5.19
		Flake	21	9.52%	23.81%	42.86%	19.05%	14.29%	μ	37.48	14.17	33.60
									σ	8.91	3.10	117.21
		Splinter	108	1.85%	12.04%	13.89%	0.93%	73.15%	μ	13.16	17.47	2.46
									σ	5.87	118.38	1.39

* percentage of each remain category bearing a percussion bulb

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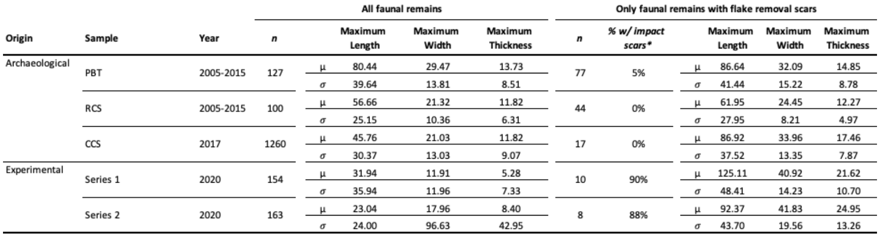
Tab. 2 Summary of the morphometric data for the samples considered in the present study and comparison with specimens bearing flake scars by sample.



			All faunal remains					Only faunal remains with flake removal scars				
Origin	Sample	Year	*n*		Maximum Length	Maximum Width	Maximum Thickness	*n*	*% w/ impact scars**		Maximum Length	Maximum Width	Maximum Thickness
Archaeological	PBT	2005-2015	127	μ	80.44	29.47	13.73	77	5%	μ	86.64	32.09	14.85
				σ	39.64	13.81	8.51			σ	41.44	15.22	8.78
	RCS	2005-2015	100	μ	56.66	21.32	11.82	44	0%	μ	61.95	24.45	12.27
				σ	25.15	10.36	6.31			σ	27.95	8.21	4.97
	CCS	2017	1260	μ	45.76	21.03	11.82	17	0%	μ	86.92	33.96	17.46
				σ	30.37	13.03	9.07			σ	37.52	13.35	7.87
Experimental	Series 1	2020	154	μ	31.94	11.91	5.28	10	90%	μ	125.11	40.92	21.62
				σ	35.94	11.96	7.33			σ	48.41	14.23	10.70
	Series 2	2020	163	μ	23.04	17.96	8.40	8	88%	μ	92.37	41.83	24.95
				σ	24.00	96.63	42.95			σ	43.70	19.56	13.26

PBT = Potential bone tools; RCS = Restricted control sample; CCS = Complete control sample (see section 4.1 for details on the sampling).

* Percentage of fragments with co-occurrence of flake removal scars and impact scars

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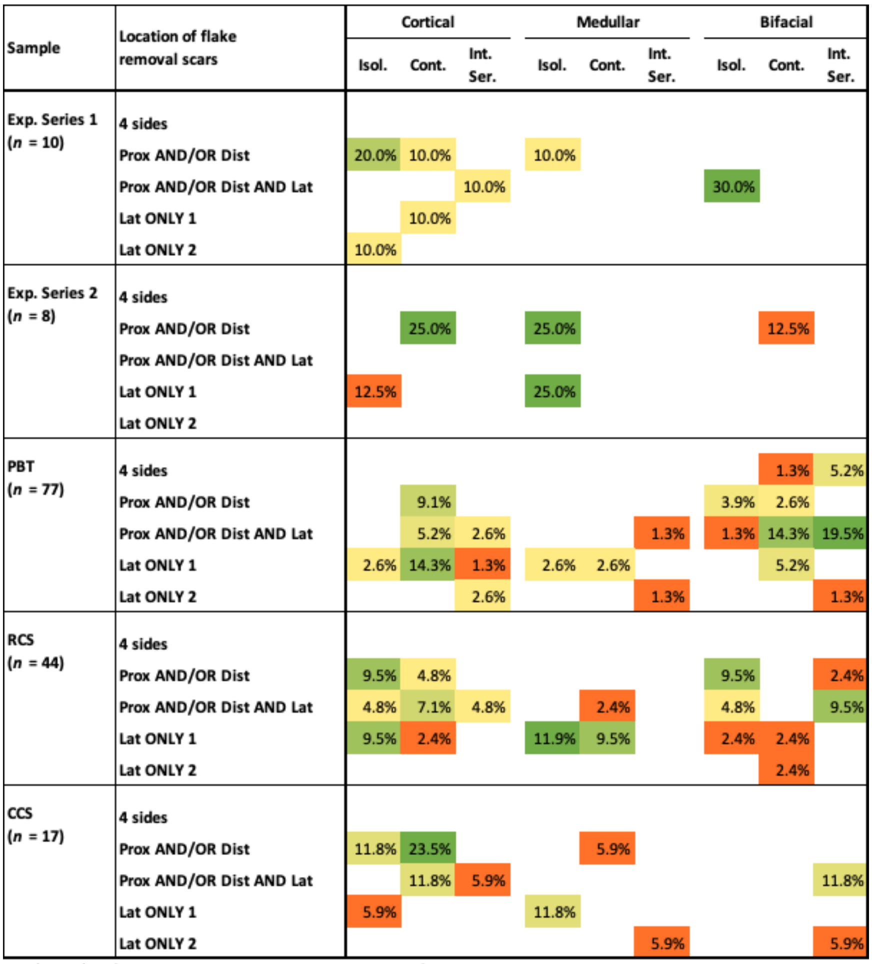
Origin	Sample	Year	*n*		Maxin Leng
Archaeological	PBT	2005-2015	127	μ	80.
				σ	39.
	RCS	2005-2015	100	μ	56.
				σ	25.
	CCS	2017	1260	μ	45.
				σ	30.
Experimental	Series 1	2020	154	μ	31.
				σ	35.
	Series 2	2020	163	μ	23.
				σ	24.

PBT = Potential bone tools; RCS = Restricted control sample; CCS = Complete contr

Tab. 3 Relative proportion for the location and arrangement of flake scars by sample considered in the present study. The colour ramp is automatically formatted from orange (low) to green (high) based on the percentage distribution for each sample to ease comparison and accounts for sample size difference.



Sample	Location of flake removal scars	Cortical			Medullar			Bifacial		
		Isol.	Cont.	Int. Ser.	Isol.	Cont.	Int. Ser.	Isol.	Cont.	Int. Ser.
Exp. Series 1 (*n* = 10)	**4 sides**									
	Prox AND/OR Dist	20.0%	10.0%		10.0%					
	Prox AND/OR Dist AND Lat			10.0%				30.0%		
	Lat ONLY 1		10.0%							
	Lat ONLY 2	10.0%								
Exp. Series 2 (*n* = 8)	**4 sides**									
	Prox AND/OR Dist		25.0%		25.0%				12.5%	
	Prox AND/OR Dist AND Lat									
	Lat ONLY 1	12.5%			25.0%					
	Lat ONLY 2									
PBT (*n* = 77)	**4 sides**								1.3%	5.2%
	Prox AND/OR Dist		9.1%					3.9%	2.6%	
	Prox AND/OR Dist AND Lat		5.2%	2.6%			1.3%	1.3%	14.3%	19.5%
	Lat ONLY 1	2.6%	14.3%	1.3%	2.6%	2.6%			5.2%	
	Lat ONLY 2			2.6%			1.3%			1.3%
RCS (*n* = 44)	**4 sides**									
	Prox AND/OR Dist	9.5%	4.8%					9.5%		2.4%
	Prox AND/OR Dist AND Lat	4.8%	7.1%	4.8%		2.4%		4.8%		9.5%
	Lat ONLY 1	9.5%	2.4%		11.9%	9.5%		2.4%	2.4%	
	Lat ONLY 2								2.4%	
CCS (*n* = 17)	**4 sides**									
	Prox AND/OR Dist	11.8%	23.5%			5.9%				
	Prox AND/OR Dist AND Lat		11.8%	5.9%						11.8%
	Lat ONLY 1	5.9%			11.8%					
	Lat ONLY 2						5.9%			5.9%

Isol. = Isolated; Cont. = Contiguous; Int. Ser. = Interspersed series
Prox = Proximal end; Dist = Distal end; Lat = Lateral edge
PBT = Potential bone tools; RCS = Restricted control sample; CCS = Complete control sample (see section 4.1)

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Sample	Location of flake removal scars	Is
Exp. Series 1 (*n* = 10)	4 sides	
	Prox AND/OR Dist	20
	Prox AND/OR Dist AND Lat	
	Lat ONLY 1	
	Lat ONLY 2	10
Exp. Series 2 (*n* = 8)	4 sides	
	Prox AND/OR Dist	
	Prox AND/OR Dist AND Lat	
	Lat ONLY 1	12
	Lat ONLY 2	
PBT (*n* = 77)	4 sides	
	Prox AND/OR Dist	
	Prox AND/OR Dist AND Lat	
	Lat ONLY 1	2
	Lat ONLY 2	
RCS (*n* = 44)	4 sides	
	Prox AND/OR Dist	9
	Prox AND/OR Dist AND Lat	4
	Lat ONLY 1	9
	Lat ONLY 2	
CCS (*n* = 17)	4 sides	
	Prox AND/OR Dist	11
	Prox AND/OR Dist AND Lat	
	Lat ONLY 1	5
	Lat ONLY 2	

Isol. = Isolated; Cont. = Contiguous; Int. Ser. = Inter
Prox = Proximal end; Dist = Distal end; Lat = Latera
PBT = Potential bone tools; RCS = Restricted contr

Tab. 4 Morphometric data on the compacta thickness and relative frequencies for natural and anthropogenic alterations recorded on the archaeological samples from Lingjing, layer 11, based on the presence or absence of flake scars on the specimens.

										Polish											
			Compacta Thickness (mm)			Carnivore				Cortical surface				Medullar surface				Edges			
	Sample	*n*	µ	σ	Root etching	Scoring	Diges-tion	Marrow extrac-tion	Cut marks	Low	Medium	High	None	Low	Medium	High	None	Low	Medium	High	None
With flake removal scars	PBT	77	9.36	4.00	42.9%	3.9%	1.3%	5.2%	33.8%	14.3%	54.5%	22.1%	9.1%	32.5%	40.3%	5.2%	22.1%	26.0%	46.8%	10.4%	16.9%
	RCS	44	9.18	5.42	43.2%	0.0%	0.0%	0.0%	18.2%	38.6%	11.4%	0.0%	50.0%	15.9%	4.5%	0.0%	79.5%	11.4%	4.5%	0.0%	84.1%
	CCS	17	8.61	3.58	58.8%	0.0%	0.0%	0.0%	0.1%	5.9%	0.0%	5.9%	0.0%	0.0%	0.0%	5.9%	94.1%	0.0%	5.9%	0.0%	94.1%
Without flake removal scars	PBT	50	6.73	2.84	30.0%	10.0%	8.0%	6.0%	24.0%	26.0%	24.0%	10.0%	40.0%	16.0%	10.0%	0.0%	74.0%	12.0%	12.0%	0.0%	76.0%
	RCS	56	7.02	4.03	32.1%	0.0%	0.0%	1.8%	14.3%	42.9%	1.8%	0.0%	55.4%	12.5%	0.0%	0.0%	87.5%	8.9%	0.0%	0.0%	91.1%
	CCS	1243	5.79	3.03	35.8%	0.3%	0.4%	2.2%	17.8%	6.4%	0.6%	0.0%	93.0%	3.9%	0.2%	0.0%	95.9%	1.2%	0.9%	0.0%	97.9%

2005 Isol. = Isolated specimens from the 2005-2015 excavations; 2005 Rand. = Randomly-selected specimens from the 2005-2015 excavations; 2017 All = Faunal assemblage from the 2017 excavation of layer 11. PBT = Potential bone tools; RCS = Restricted control sample; CCS = Complete control sample (see section 4.1 for details on the sampling).

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