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Animals for Tools: The Origin and Development of Bone Technologies in China

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The origin and development of bone technologies in China are reviewed in the light of recent discoveries and compared to trends emerging from the European and African archaeological records. Three categories of osseous tools are targeted: 1) unmodified bone fragments bearing traces of use in technological activities; 2) bone fragments modified to a variable extent with techniques generally used in stone technologies; 3) osseous fragments entirely shaped with techniques fit for the manufacture of formal bone tools. Early evidence of bone technologies in China are sporadically found in contexts dated between 1.8 and 1.0 Ma. By the late MIS6–early MIS5, bone tools are well-integrated in the technological systems of Pleistocene populations and the rules guiding their use appear increasingly standardized. In addition, the first evidence for the use of osseous material in symbolic activities emerges in the archaeological record during this period. Finally, between 40 and 35 ka, new manufacturing techniques and products are introduced in Late Palaeolithic technological systems. It is first apparent in the manufacture of personal ornaments, and followed by the production and diversification of formal bone tools. By that time, population dynamics seem to become materialized in these items of material culture. Despite regional specificities, the cultural trajectories identified for the evolution of bone technologies in China seem entirely comparable to those observed in other regions of the world.

Keywords: Pleistocene, bone tools, cultural evolution, symbolism, archaic humans, *Homo sapiens*

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1 INTRODUCTION

The evolution of bone technologies represents a key issue in paleoanthropological research. First, from a subsistence perspective, the origin of bone tools signals a major shift in the way past populations perceived the animal species at their disposal, specifically when faunal resources' utility expanded from their primary uses, i.e., meat consumption, hide processing, fat use, and fuel, to include the manufacture and use of cultural items made of hard animal tissues. Second, from a social perspective, bone tools represent an ideal proxy to investigate social dynamics. Indeed, owing to their mechanical properties, prehistoric populations could impose a form to the object by applying a sequence of adapted techniques, e.g., scraping, incision, grinding, gouging, etc. When studying implements produced with these techniques, archaeologists can document variation in how knowledge was implemented for the manufacture of various tool types, differentiate between the form and function of an object, and explore topics such as technological organization, pattern of cultural transmission, population dynamics, etc.

Expanding on Klein (2009) definitions, it is possible to distinguish three main categories of bone tools. The first category includes unmodified osseous fragments bearing clear evidence of their use. The second comprises fragments intentionally modified albeit with techniques usually devoted to the manufacture of stone tools. The third refers to osseous fragments entirely shaped with techniques fit to transform hard animal tissues. The first two categories are usually referred to as "expedient tools" while the third is known as "formal tools" (Klein, 2009). Here, the aim is to provide a synthesis on the tipping points that punctuated the origin and development of these broad artefactual categories and compare recent evidence from China to the African and European archaeological record. This review highlights that, despite some regional specificities, the cultural trajectories identified for the evolution of bone technologies in China are largely comparable to those observed in other regions of the world.

2 PLEISTOCENE OSSEOUS TECHNOLOGY IN AFRICA AND EUROPE

Four tipping points can be identified in the origin and development of bone technologies in Africa and Europe. The first tipping point occurs between 2.0 and 1.5 Ma, a period at which the first occurrences of the use of bone appear simultaneously in the South and East African archaeological records. In South Africa, a number of sites attests to the use of mostly unmodified bone fragments as digging implements by *Australopithecus robustus* (Brain and Shipman, 1993; Backwell and d'Errico, 2001; Backwell and d'Errico, 2008; d'Errico and Backwell, 2003; Val and Stratford, 2015; Stammers et al., 2018; Hanon et al., 2021). Meanwhile, in East Africa, occupation layers at Olduvai Bed I and II yielded numerous bone fragments bearing evidence of intentional shaping. Technological and use-wear studies suggest that early members of our genus, *Homo*, used these implements for hide-working, butchery, digging, stone knapping and, possibly, hunting activities (Backwell and d'Errico, 2004; Pante et al., 2020). It remains unclear why organic technologies were integrated in the technological systems of our ancestors. However, it appears reasonable to believe that activities attested since at least 2.6 Ma, such as stone knapping (Harmand et al., 2015; Lewis and Harmand, 2016), marrow extraction (Domínguez-Rodrigo et al., 2005), and wood working (Lemorini et al., 2014, 2019), may have allowed early hominins to recognize the technological potential of osseous materials and equipped them with the skills required to modify and utilize bone flakes.

Between 1.5 Ma and the second half of the Middle Pleistocene, the archaeological record yielded only a handful of evidence for the use or modification of osseous remains for technological purpose. Most often, these items correspond to bone retourchers, i.e., bone fragments used in stone knapping activities (Goren-Inbar, 2011; Smith, 2013; Moigne et al., 2016), or bifaces made on *Elephantidae* long bone fragments (Kretzoi and Dobosi, 1990; Mania and Mania, 2003; Rabinovich et al., 2012; Sano et al., 2020). In rare occasion, hard animal remains bearing incised patterns (Mania and Mania, 1988; Sirakov et al., 2010; Joordens et al., 2015) are interpreted as early experimentations with this raw material either to permanently record information or to express some form of symbolic behaviors. Collectively, these occurrences, albeit scattered in both time and space, suggest that the use osseous materials for technological purposes was never completely abandoned by prehistoric populations during this period.

The second tipping point occurs mainly in Europe at the onset of the Marine Isotope Stage (MIS) 9. Between ~350 and 300 ka, bone bifaces and retouchers become commonplace (Naldini et al., 2009; Anzidei et al., 2012; Moncel et al., 2012; Blasco et al., 2013; Daujeard et al., 2014; Boschian and Saccà, 2015; Santucci et al., 2016; Villa et al., 2021). Furthermore, the archaeological record attests to a noticeable increase in the diversity of expedient bone tool morphology and of the use-wear development on them, possibly reflecting an expansion in the behavioral spectrum for which they were used (Rosell et al., 2011; Julien et al., 2015; Di Buduo et al., 2020; Bonhof and van Kolfschoten, 2021). From the MIS9 onward, the use of expedient tools becomes a lasting aspect of Pleistocene technological systems alongside the multiple innovations that define the third and fourth tipping points (e.g., Daujeard, 2007; Burke and d'Errico, 2008; Verna and d'Errico, 2011; Mallye et al., 2012; Tartar, 2012; Abrams et al., 2014; Daujeard et al., 2018; Yeshurun et al., 2018; Baumann et al., 2020; Hallett et al., 2021).

The third tipping point is restricted to the African continent. Between 90 and 65 ka, a number of formal bone tools appear in the archaeological record. The distribution of each type presents a marked pattern of regionalization with bone knives and smoothers found in Northeast Africa (Bouzouggar et al., 2018; Hallett et al., 2021), barbed points in Central Africa (Yellen, 1998), and awls, wedges and hunting implements in South Africa (Henshilwood et al., 2001; d'Errico and Henshilwood, 2007; d'Errico et al., 2012a; Bradfield et al., 2020). In Africa, the emergence of formal bone tools is broadly contemporaneous with the appearance of personal ornaments (d'Errico et al., 2005; d'Errico et al., 2008; d'Errico et al., 2009; Vanhaeren et al., 2006, 2019; Bouzouggar et al., 2007; Bar-Yosef Mayer et al., 2009; Val et al., 2020), although recent discoveries from Bizmoune Cave, Morocco, indicates personal ornaments may have been manufactured up to 50 millennia prior to the first bone tools in this particular region (Sehasseh et al., 2021). Interestingly, both personal ornaments and formal bone tools disappear from the African archaeological record *c*. 60 ka. This apparent hiatus in material culture lasts for roughly 15 millennia.

Contrary to the aforementioned, the fourth tipping point is not restricted to a particular region and/or continent; it is indeed a global phenomenon. From 45 ka, formal bone tools and personal ornaments make a lasting reappearance in the archaeological record, this time in multiple regions of the Old World. Evidence from Europe (d'Errico et al., 2003; Zilhão et al., 2010; Caron et al., 2011; d'Errico et al., 2012c; Soressi et al., 2013; Julien et al., 2019; Sano et al., 2019; Arrighi et al., 2020; Velliky et al., 2021), the Levant (Kuhn et al., 2001; Tejero et al., 2016; Tejero et al., 2018; Bar-Yosef Mayer, 2020; Tejero et al., 2020), East and South Africa (d'Errico et al., 2012b; d'Errico et al., 2020),

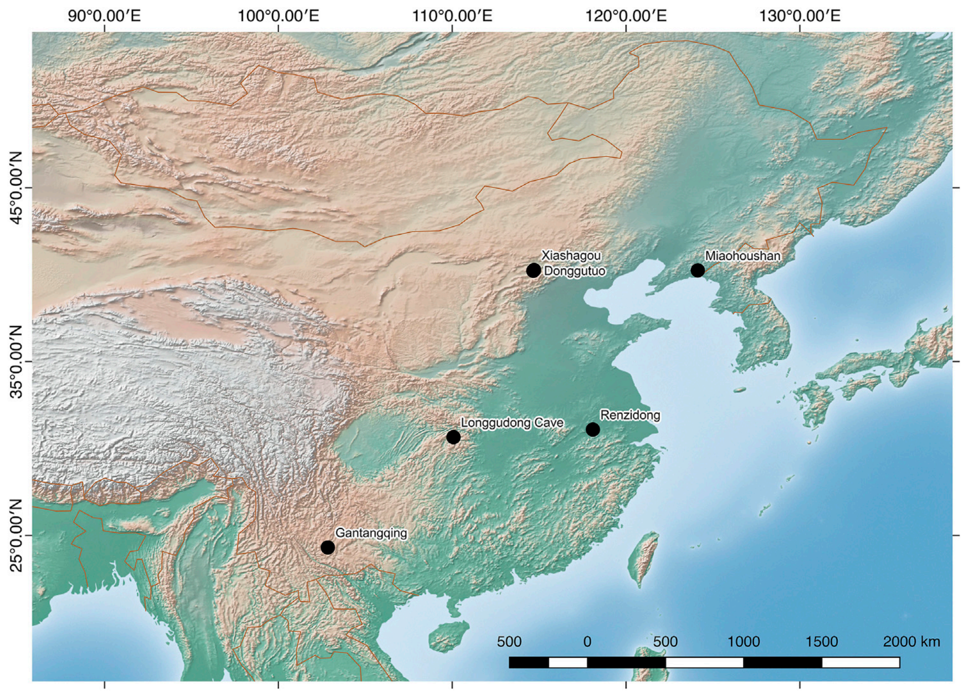

FIGURE 1 | Distribution of Chinese Lower Paleolithic sites where osseous technology was reported in the literature (see **Table 1** for details). Map made by LD using QGIS v. 2.14.3-Essen (Free Software Foundation, Inc., Boston) and free vector and raster from Natural Earth (naturalearthdata.com).

South and Central Asia (Golovanova et al., 2010; Perera et al., 2016; Krivoshapkin et al., 2018; Shalagina et al., 2018; Belousova et al., 2020; Langley et al., 2020; Shunkov et al., 2020) as well as the Asian Pacific Island and Australia (O'Connor et al., 2014; Langley et al., 2016b; Langley et al., 2016a; Langley et al., 2019; Langley et al., 2021) attests to the penecontemporaneous development of a variety of formal bone tool types, the diversification of the manufacturing processes and techniques, the convergent innovation in the production of hunting armatures and the noticeable expansion in the variety of symbolic material culture items.

3 PLEISTOCENE BONE TECHNOLOGY IN CHINA

In light of the trends identified above, one may wonder to what extent the Chinese archaeological record is comparable to the rest of the Old World when it comes to the origin and development of osseous technologies. This question is even more pertinent when we consider the central place occupied by this region in paleoanthropological studies, especially with regard to Pleistocene hominin dispersal events and complex population dynamics (Wu, 2004; Shang et al., 2007; Hou and Zhao, 2010; Keates, 2010; Liu et al., 2010; Kaifu and Fujita, 2012; Fu et al., 2013; Shen et al., 2013; Bae et al., 2014; Liu et al., 2015; Zhu et al., 2015; Bae et al., 2017; Cai et al., 2017; Kaifu, 2017; Li et al., 2017; Martinón-Torres et al., 2017; Yang et al., 2017; Bae et al., 2018; Chen et al., 2019; Dennell et al., 2020; Massilani et al., 2020; Zhang et al., 2020; Curnoe et al., 2021; Higham and Douka, 2021; Martinón-Torres et al., 2021; Mao et al., 2021; Sun et al., 2021). In what follows, three tipping points are identified.

Much like the rest of the Old World, the first tipping point relates to the first occurrences of osseous technology in the archaeological record. A number of sites suggests a very ancient origin for the intentional modification of bones for technological purposes (**Figure 1**; **Table 1**). Between 1.8 and 1.0 Ma, key sites include Longgudong Cave, Renzidong, and Donggutuo (Wei, 1985; Zhang et al., 2000; Zhu et al., 2003; Li, 2004; Hou and Zhao, 2010). In all these cases, the reported tools consist of osseous fragments modified by direct percussion, i.e., in a fashion similar to stone knapping. From 1.0 Ma and throughout the Late Paleolithic, reports of similar technology are often reported in the literature (**Figures 2**, **3**; **Table 1**), although some evidence would perhaps benefit from a reassessment using modern analytical methods to ensure the anthropogenic nature of the modification. Thus far, however, previous reviews have highlighted a subtle change over time when it comes to the modification of osseous remains through direct percussion (An, 2001; Feng, 2004; Wei G. et al., 2017). For most of the Early Paleolithic, the tools are generally crude and simple, and the flakes are mainly removed from the distal end of bone fragments to produce pointed implements. From the Middle and throughout the Late Paleolithic, direct percussion is used to shape the long edges of osseous fragments by a series of successive blows. In some cases, overlapping flake removal scars appear to indicate these long cutting edges were at times reshaped, perhaps to increase the longevity of the tools for whatever tasks they were considered fit (Feng, 2004).

TABLE 1 | Summary of occurrence of Pleistocene osseous technology in China.

Site	County	Province	Cultural attribution	Tool types			References
				Unmodified bone fragments with traces of use	Bone fragments modified by direct percussion	Formal bone tools	
Donggutuo	Yangyuan	Hebei	Lower Paleolithic		X		Wei (1985), Zhu et al. (2003)
Gantangqing	Jiangchuan	Sichuan	Lower Paleolithic	X	X		Zhang et al. (1989), Yunnan Institute of Cultural Relics and Archaeology and Liu (2016)
Longgudong Cave	Jianshi	Hubei	Lower Paleolithic		X		Hou and Zhao (2010)
Miaohoushan	Benxi	Liaoning	Lower Paleolithic		X		Liaoning Provincial Museum and Benxi Municipal Museum (1986)
Renzidong	Fanchang	Anhui	Lower Paleolithic		X		Zhang et al. (2000), Hou and Zhao (2010)
Xiashagou	Yangyuan	Hebei	Lower Paleolithic	X	X		Wang et al. (1988)
Bashiyi Quarry	Jiulongpo	Chongqing	Middle Paleolithic		X		Wei et al. (2017b)
Dadong	Panxian	Guizhou	Middle Paleolithic		X		Miller-Antonio et al. (2000)
Dingcun	Xiangfen	Shanxi	Middle Paleolithic	X	X		Tao and Wang (1987)
Jiangjiawan	Qingyang	Gansu	Middle Paleolithic		X		Xie and Zhang (1977)
Jujiayuan	Qingyang	Gansu	Middle Paleolithic	X	X		Xie and Zhang (1977)
Lingjing	Xuchang	Henan	Middle Paleolithic	X	X		Li and Shen (2010), Li and Shen (2011), Doyon et al. (2018), Doyon et al. (2019), Doyon et al. (2021)
Longtandong	Hexian	Anhui	Middle Paleolithic	X	X		Lu (1990)
Longtanshan Cave 1	Chenggong	Yunnan	Middle Paleolithic		X		Hu (1977)
Loufangzi	Qingyang	Gansu	Middle Paleolithic		X		Xie and Zhang (1977)
Nanliang	Houma	Shanxi	Middle Paleolithic		X		Hu (1961)
Wulanmulun	Ordos (City)	Inner Mongolia	Middle Paleolithic		X		Hou et al. (2012), Zhang L.-m. et al. (2016)
Xujiayao	Yanggao	Shanxi	Middle Paleolithic	X	X		Jia et al. (1979)
Zhaocun	Qian'an	Hebei	Middle Paleolithic		x		Zhang (1989)
Zhijidong	Wangzongdain	Henan	Middle Paleolithic		X		Zhang and Liu (2003)
Zhoujiayoufang	Yushu	Jilin	Middle Paleolithic		X		Sun et al. (1981)
Zhoukoudian Loc. 1	Beijing	Beijing	Middle Paleolithic		X		Jia (1959), Jia (1989)
Jinniushan	Yingkou	Liaoning	Middle and Upper Paleolithic		X	X	Jinniushan Joint Excavation Team (1978)
Yumidong	Wushan	Chongqing	Middle and Upper Paleolithic		X		He (2019)
Bailiandong	Liuzhou	Guangxi	Upper Paleolithic			X	Lotus Cave Science Museum et al. (1987)
Baiyanjiaodong	Puding	Guizhou	Upper Paleolithic		X	X	Cai (2012)
Beiyaowan	Heshun	Shanxi	Upper Paleolithic		X		Wu and Chen (1989)

(Continued on following page)

TABLE 1 | (*Continued*) Summary of occurrence of Pleistocene osseous technology in China.

Site	County	Province	Cultural attribution	Tool types			References
				Unmodified bone fragments with traces of use	Bone fragments modified by direct percussion	Formal bone tools	
Chuandong	Puding	Guizhou	Upper Paleolithic		X	X	Mao and Cao (2012), He (2019)
Chuanfandong	Sanming	Fujian	Upper Paleolithic			X	Chen et al. (2001)
Dahe	Fuyuan	Yunnan	Upper Paleolithic		X	X	Ji (2008)
Daxingtun	Angangxi	Heilongjiang	Upper Paleolithic		X		Gao (1988)
Dushizai	Yangjiang	Guangdong	Upper Paleolithic			X	Zhou (1994)
Gezishan Loc. 10	Wuzhong	Ningxia Hui Autonomous Region	Upper Paleolithic			X	Zhang S. et al. (2019)
Gulongshan	Wafangdian	Liaoning	Upper Paleolithic	X	x		Zhou et al. (1990)
Laolongdong	Yuxi	Yunnan	Upper Paleolithic			x	Bai, (1998)
Liyuzui	Liuzhou	Guangxi	Upper Paleolithic			X	Zhou (1994)
Longquandong	Luanchuan	Henan	Upper Paleolithic			X	School of History Beijing Normal University et al. (2017)
Ma'anshan	Tongzi	Guizhou	Upper Paleolithic			X	Zhang S. et al., 2016
Ma'anshan	Yangyuan	Hebei	Upper Paleolithic			X	Xie et al. (2006)
Maomaodong	Yixing	Guizhou	Upper Paleolithic	X		X	Cao (1982)
Shiyu	Shuozhou	Shanxi	Upper Paleolithic		x		Zhang (1991)
Shizitan Loc. 29	Shizihe	Shanxi	Upper Paleolithic			X	Song et al. (2016), Song et al. (2019), d'Errico et al. (2018)
Shuidonggou Loc. 1	Binhe	Ningxia Hui Autonomous Region	Upper Paleolithic			X	Jia et al. (1964)
Shuidonggou Loc. 2	Binhe	Ningxia Hui Autonomous Region	Upper Paleolithic		X		Madsen et al. (2001)
Shuidonggou Loc. 12	Binhe	Ningxia Hui Autonomous Region	Upper Paleolithic			X	Zhang Y. et al. (2016), Zhang Y. et al. (2019), d'Errico et al. (2018), Zhang et al. (2018)
Wangfujing	Beijing	Beijing	Upper Paleolithic	X	X		Li et al. (2000)
Xianrendong	Shoushan	Jilin	Upper Paleolithic		X		Chen and Li (1994)
Xiaogushan	Haicheng	Liaoning	Upper Paleolithic			X	Huang et al. (1986)
Xuetian	Wuchang	Heilongjiang	Upper Paleolithic		X		Yu (1988)
Yancoudong	Guiyang	Hunan	Upper Paleolithic			X	Zhang (1965), Li (1982)
Yanjiagang	Harbin (City)	Heilongjiang	Upper Paleolithic		X		Heilongjiang Provincial Cultural Relics Management Committee et al. (1987)
Yuchanyan	Daoxian	Hunan	Upper Paleolithic			X	Yuan (2002)
Zhoukoudian Upper Cave	Beijing	Beijing	Upper Paleolithic	X	X	X	Pei (1939), d'Errico et al. (2018), d'Errico et al. (2021)
Ziyangren	Ziyang	Sichuan	Upper Paleolithic			X	Zhang (1965)

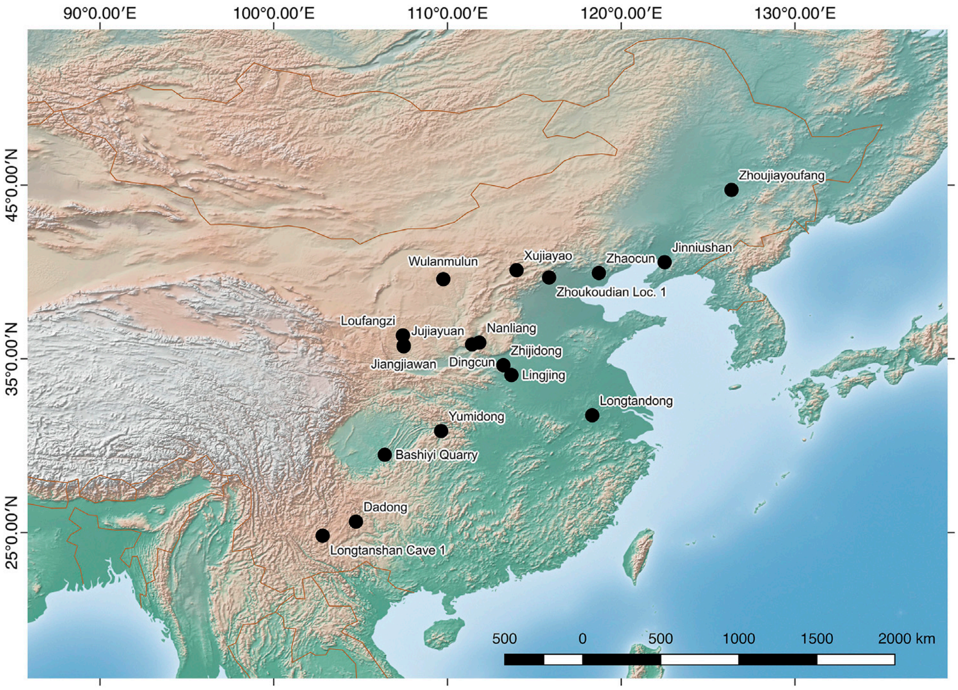

FIGURE 2 | Distribution of Chinese Middle Paleolithic sites where osseous technology was reported in the literature (see **Table 1** for details). Map made by LD using QGIS v. 2.14.3-Essen (Free Software Foundation, Inc., Boston) and free vector and raster from Natural Earth (naturalearthdata.com).

In contrast to what is observed in Europe during the MIS9, one may wonder whether any hint exists in favor of a functional diversification of the expedient bone tools in China during the Middle Pleistocene. The case of Lingjing, layer 11, an early Late Pleistocene kill/butchery site dated between 125 and 105 ka, provides a peculiar outlook on this issue. This occupation layer has yielded a rich and well-preserved faunal assemblage as well as important hominin remains (Li et al., 2017). Recent research conducted by zooarchaeologists, taphonomists and technologists allowed the identification of dozens of bone tools and revealed an unsuspected behavioral complexity. The microscopic observation of bone surface modifications permitted the recognition of antler soft hammers, i.e., tools used to remove flakes from a block during stone knapping (Doyon et al., 2018); bone retouchers as well as passive and active pressure flakers made of bone and antler, i.e., three tool types used to shape and retouch the cutting edges of stone implements but used in distinct motions (Doyon et al., 2019); and, equid and bovid metapodials used in long bone fracturing activities to access the marrow (van Kolfschoten et al., 2020; Bonhof and van Kolfschoten, 2021). Furthermore, two large mammal rib bone fragments bearing a pattern consisting of sequential linear incisions–one of them preserves remnants of ochre residues between and within the lines on its surface–suggest the visitors at the site may have intended to permanently record information on these remains or express some form of symbolic behaviors while producing the patterns (Li et al., 2019). During the 2005–2018 excavations of layer 11, some osseous fragments were isolated owing to the multiple flake removal scars they bear and, in some cases, the presence of an unusual polish (Li and Shen, 2010, 2011; Doyon et al., 2021). Experimentation in fracturing horse long bones for marrow extraction evidenced this activity could not account for the number and relative position of the flake removal scars observed on many archaeological specimens. It was therefore suggested that a sub-sample of 56 items were deliberately modified and could be interpreted as expedient bone tools (Doyon et al., 2021). Finally, morphometric comparison of these tools yielded surprising results. Among bone retouchers, the Lingjing visitors appear to have selected cervid metapodials to use them over long periods of time. These specimens present a high degree of standardization compared to the other large mammal long bone fragments used as retouchers and found at the site. This morphometric standardization was achieved by the marginal shaping through direct percussion, which likely increase the tool's prehensility and ergonomic (Doyon et al., 2018). Likewise, when comparing the dimension of the stone tools and the bone fragments with flake removal scars interpreted as expedient tools, a morphometric continuum is demonstrated, which appears to indicate a functional complementarity between the two aspects of material culture. Given the site function, it was hypothesized these bone tools may have been used in butchery and carcass processing activities (Doyon et al., 2021). Collectively, the results from Lingjing suggest we are in presence of a long-lasting tradition. The breath of activities in which bone implements are used, the evident selection in raw material for tools devoted to specific activities or receiving particular care, and the morphometric complementarity between lithic and bone

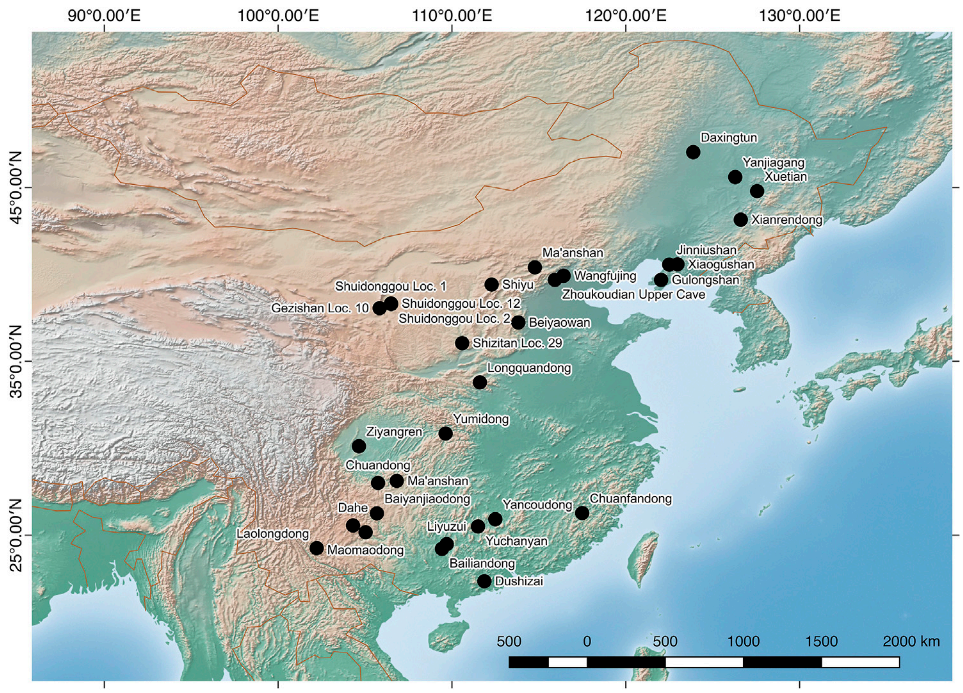

FIGURE 3 | Distribution of Chinese Upper Paleolithic sites where osseous technology was reported in the literature (see **Table 1** for details). Map made by LD using QGIS v. 2.14.3-Essen (Free Software Foundation, Inc., Boston) and free vector and raster from Natural Earth (naturalearthdata.com).

tools are all indicators suggesting that a functional diversification in osseous technologies was well-established by the end of MIS6 and the onset of MIS5. In this sense, Lingjing represents, in and of itself, a second tipping point in the evolution of Chinese Pleistocene bone technology. Future research on the origin of this cultural adaptive system may very likely push back the timing of this functional diversification, and perhaps make it comparable to what is observed in Europe.

The third tipping point occurs between 40 and 35 ka. As it was the case in the rest of the Old World, this period testifies to the emergence of formal bone tools both in North and South China (**Figure 3**; **Table 1**). These two regions attest to a convergent evolution in hunting implements. Indeed, the barbed and projectile armatures from Xiaogushan in the North (Huang et al., 1986; Zhang et al., 2010) are broadly contemporaneous with the barbed implements from Ma'anshan in the South (Zhang L.-m. et al., 2016). Throughout the Late Paleolithic, a diversification in formal bone tool types is apparent in the Chinese archaeological record (e.g., Qu et al., 2013; Zhang S. et al., 2016; Zhang et al., 2018; d'Errico et al., 2018; Wang et al., 2020). Furthermore, manufacturing techniques befitted for the transformation of osseous materials are being developed. Some techniques, such as scraping, incising, gouging, or grooving, are identical to those developed in the rest of the Old World. Others, however, appear to be more regionally circumscribed. This is the case for grinding, an ubiquitous technique used in formal bone tool manufacture in Asia during the Late Paleolithic (Rabett and Piper, 2012; O'Connor et al., 2014; Aplin et al., 2016; Zhang Y. et al., 2016; Perera et al., 2016; Li et al., 2020), yet, seldom observed in European Upper Paleolithic (Camps-Faber, 1976; d'Errico et al., 2012c; Goutas, 2013; Langley, 2016) or in African Middle Stone Age contexts (d'Errico and Henshilwood, 2007; Backwell and d'Errico, 2016; Vanhaeren et al., 2019). Outside Asia, grinding only becomes a common shaping technique in Africa during the Later Stone Age (Yellen, 1998; Bradfield, 2016). Likewise, at the end of the Late Paleolithic, past populations in North China appear to have specifically selected burnt bones, if not deliberately heated bone fragments in an anaerobic environment to change the color of the whole cortical bone rather than only its surface, to manufacture portable artwork (Li et al., 2020). Although bone discoloration can be achieved through multiple ways (e.g., Bradfield, 2018), a similar process has only been reported for the manufacture of blacken shell beads from Blombos Cave (d'Errico et al., 2015). Finally, a number of North Chinese sites suggests that the emergence of personal ornaments preceded the first occurrences of formal bone tools in the region by a few millennia. This is the case for instance at Shizitan, Shuidonggou and Zhoukoudian Upper Cave (Wei et al., 2016; Wei Y. et al., 2017; Song et al., 2017; d'Errico et al., 2018; d'Errico et al., 2021).

4 DISCUSSION

The present review on the origin and development of osseous technologies in the Old World, and the particular focus given to the Chinese archaeological record, sets the stage for a comparison of the cultural trajectories at a regional and global scales. When the timing and nature of the tipping points are considered, it becomes apparent that these trajectories are broadly similar. Despite an early appearance of bone tools in East and South Africa, evidence from China suggests that the first hominins whom dispersed in this region were carrier of a set of knowledge which allowed them to modify butchery and carcass processing by-products for technological purposes. The numerous reports from Early, Middle and Late Pleistocene contexts indicate this aspect of material culture remained in the toolkit of the populations that lived in China throughout this epoch.

From MIS9 onward, two lines of evidence indicates that the functional diversification of expedient bone tools observed in Europe is perhaps not restricted to this region, but could, in fact, constitute a trend that extends across the Eurasian continent. First, a clear difference emerges in the shaping of expedient tools during this period in China. Although direct percussion remains the predominant shaping technique, its application aims to produce long cutting edges rather then pointed objects. Second, the behavioural standardization illustrated at Lingjing is comparable to a similar trend documented in Europe for the manufacture and use of bone retouchers (Daujeard et al., 2014; Costamagno et al., 2018; Martellotta et al., 2020). The same is true for the tool types found at Lingjing, which bears numerous resemblances with those found at Schöningen for instance (Julien et al., 2015; Bonhof and van Kolfschoten, 2021). Collectively, these observations suggest that Lingjing, rather than representing an outlier in the Chinese archaeological record, likely provides a snapshot on a regional cultural trajectory that may become more and more comparable with the European one with future discoveries.

The last similitude refers to the emergence of formal bone tools. We now have ample clues in favor of a convergent cultural innovation throughout the Old World around 45 ka. The Chinese archaeological record shows this development is contemporaneously occurring in East Asia as well. Across the world, this cultural change appears closely linked with the development of hunting armatures and a paraphernalia of other tool types, and signals an increase complexification in prehistoric technological organization. It must be stressed here, however, that the emergence of formal tools didn't entail the abandonment of expedient bone tools by Upper and Late Paleolithic populations. Quite the contrary, formal bone tools augmented the pre-existing toolkit they inherited. This accretion process likely signals an increase reliance on complex technologies by these human groups (Kuhn, 2020). The easy access to workable skeletal remains from hunting and carcass processing activities, the lighter weight of bone technologies compared to lithic implements, their durability and maintenance properties (*sensu* Bleed, 1986; Bamforth, 1986) were likely key factors favouring the adoption of this lasting innovation by highly mobile hunter-gatherer populations.

Two differences stand out when comparing the cultural trajectories from China to those from the rest of the Old World. First, to this day, evidence for an "early" emergence of formal bone tools is restricted to the African continent between 90 and 65 ka. This phenomenon is even more peculiar when we consider the pattern of regionalization in tool type distribution and the fact that this category of osseous technology abruptly disappears from the archaeological record after 60 ka (see below). Second, when formal bone tools reemerge around 45 ka, the technical know-hows implemented for their manufacture show subtle, yet lasting, variation in their distribution. A potent example of this variation lies in the ubiquity of grinding used as a shaping technique in Asia and Africa, and its relative absence in other part of the world.

Based on the above review and regional comparison, future studies on osseous technology should address a number of research priorities. These research prospects are grouped below by main categories of bone tools. They primarily aim to fill the gaps in our understanding of this aspect of material culture to provide a complementary perspective to lithic tools in cultural evolution studies.

Thus far, research on "expedient tools" have mainly focused on bone retouchers, a tool type that lies at the interface between lithic and bone technologies. We now have ample evidence that early hominin technological adaptive systems also included the exploitation of skeletal elements for other activities. Therefore, future studies should be articulated along two main axes. First, more experimental programs must be implemented to test the criteria suggested to recognize intentionally modified osseous fragments (e.g., Backwell and d'Errico, 2004; Doyon et al., 2021). Such criteria would allow zooarchaeologists and taphonomists to quickly identify faunal remains that should be subjected to a thorough technological analysis. Second, and in parallel with the first axis, more use-wear studies, both experimental and archaeological, should be undertaken to establish the activities in which these tools served a purpose (e.g., Shipman and Rose, 1983; Baumann et al., 2020; Mateo-Lomba et al., 2020). The development of use-wear method in China, in particular, would allow archaeologists to move away from typological approaches when dealing with expedient tools (e.g., An, 2001). Indeed, a major setback of such classification systems, too often inspired by lithic typology, lies in the fact that these tool types carry a functional meaning that may not correspond to the activities for which they were used. Instead of reducing the development of osseous technologies to a succession of tool types, studies in cultural evolution should focus more on the choices made by past population regarding the selection of skeletal elements, the methods used to modify them and the role these objects fulfilled in the technological system. From a chronological standpoint, these two research axes should not be restricted to period preceding the emergence of formal bone tools; they must also be extended to more recent Paleolithic periods, i.e., Upper and Late Paleolithic, to depict a clearer picture on how different osseous technological adaptations co-evolved in time.

Two main research axes are also identified for the study of "formal bone tools." First, although these tools have historically received most of the attention in archaeology, owing in part to the ease to identify them and for their crucial role in establishing chrono-cultural timelines, the nature of the data available to address questions related to cultural evolution is fairly uneven at a global scale. While data stemming from the application of the *chaîne opératoires* concept is commonplace in Europe, its application to the Chinese archaeological record remains exceptional (for a review, see Yin et al., 2021). However, this tool allows to detail the decision process implemented by prehistoric groups for the manufacture and use of bone technologies. Variation in these decisions are extremely instructive; they can help define boundaries between groups carrying different sets of knowledge as well as establish whether or not interactions existed between these groups. These variations can also be correlated with environmental and/or social variables to better apprehend the mechanisms and processes at the origin of change in the different cultural adaptive systems. Second, regional- and global-scale syntheses using multivariate analyses are essential in the near future. In spite of being usually restricted to a single tool type (Stordeur-Yedid, 1979; d'Errico et al., 2018; Doyon, 2019; Doyon, 2020), these syntheses illustrate their aptitude to retrace cultural phylogenies, explore topic such as technological organization and population dynamics during the Pleistocene. Bone technologists may find inspiration in analogous projects undertaken to investigate the variation in personal ornaments (Vanhaeren and d'Errico, 2006; McAdam, 2008; d'Errico and Vanhaeren, 2015; Rigaud et al., 2015; Rigaud et al., 2018; Balme and O'Connor, 2019; d'Errico et al., 2021), and confront their results to other aspects of material culture to provide a nuanced outlook on topics such as cultural innovations and transmission during the Pleistocene. From a chronological standpoint, a key question that needs to be tackled relates to the circumstances surrounding the *circa* 15-ka hiatus in "formal bone tools" between their first emergence and disappearance in the African record, and their convergent reappearance across the Old World around 45 ka. Addressing such issue requires to confront multiple regional cultural trajectories and engage in a sustained dialogue with specialists from other disciplines, e.g., paleoanthropology, paleogenetic, paleoenvironmental sciences, etc., in an attempt to comprehend whether, and to what extent, changes in osseous–and other–technology throughout the Pleistocene match the complex dynamics reflected in the evolution of our genus.

AUTHOR CONTRIBUTIONS

LD designed the study. MS and LD conducted the study. LD wrote the initial version of the manuscript. MS and LD reviewed and edited the final version of the manuscript.

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