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ON THE USE OF METAPODIALS AS TOOLS AT SCHÖNINGEN 13II-4

Abstract

The Schöningen 13II-4 "Spear Horizon" provides an unparalleled view of Middle Pleistocene hominin technological and subsistence behaviours. The site preserves the remains of more than fifty butchered horses in addition to other large mammals, but the associated lithic assemblage is relatively small. As a complement to the lithic tools, Middle Pleistocene hominins at Schöningen used a variety of bone implements related to stone tool manufacture and maintenance. Here we describe a collection of metapodials from the Schöningen 13II-4 Spear Horizon interpreted as soft hammers. These bones bear consistent patterns of damage to the proximal and distal ends, indicating their repeated use in heavy percussive activities. We present the results of preliminary experimental studies aimed to better understand how and for what purposes these implements were used, and we conclude that the damage to the Schöningen metapodials is consistent with use in both stone working and bone breaking tasks. Based on the apparent lack of large stone cobbles in the lithic assemblage, the metapodial tools likely replaced hammerstones in the lithic *chaîne opératoire* and in processing bones for marrow. While it is clear that metacarpals and metatarsals were preferred over other bones for use as soft hammers, there is a relative lack of metapodials among the roughly 15,000 faunal remains in the entire assemblage. This pattern of skeletal part representation indicates that metapodials may have been transported away from the Schöningen 13II-4 site to be used at other locations across the landscape. Together with the well-known spears, these bone implements underscore the importance of non-lithic technologies for Middle Pleistocene hominins.

Keywords

Schöningen 13II-4; Middle Pleistocene; Non-lithic technology; Soft hammer; Metapodial

Introduction

The Schöningen 13II-4 "Spear Horizon" site rose to fame upon the discovery of multiple wooden spears preserved within a Middle Pleistocene-aged lakeshore deposit (Thieme, 1997). These 300,000-year-old weapons were recovered alongside a large accumulation of butchered animal remains, providing an unparalleled view of the hunting lifeways and butchery practices of Middle Pleistocene hominins.

Among the faunal remains, dozens of large mammal limb bone shaft fragments show traces of damage produced by retouching and re-sharpening lithic tools (Voormolen, 2008; van Kolfschoten et al., 2015b). Such "retouchers" are ubiquitous components of European Upper and Middle Palaeolithic tool-kits and have been recognised at a number of Lower Palaeolithic sites. Bone and antler retouchers from the 500,000-year-old site of Boxgrove, UK (Roberts and Parfitt, 1999) demonstrate the ancient origin of this technology, and further examples are known from several Lower Palaeolithic archaeological deposits in France, Spain, and the Levant (e.g., Blasco et al., 2013; Rosell et al., 2015; Moigne et al., 2016). Most of these early sites yielded only a few limb bone fragments with pits and scores typical of retouchers, whereas the Schöningen assemblage includes dozens of bone implements made on a variety of skeletal parts from several species (Voormolen, 2008; van Kolfschoten et al., 2015b). This flexibility in the selection of different bones as raw material displayed at Schöningen signifies an extraordinarily sophisticated approach to bone tool technology that is generally not granted to hominins of such antiquity.

A further distinctive component of the bone technology at Schöningen is a collection of horse metacarpals and metatarsals with a peculiar pattern of battering damage to the proximal and distal ends (**Figure 1**), a small sample of which have been previously described by Voormolen (2008) and van Kolfschoten et al. (2015b) who interpreted the damage as resulting from heavy-duty hammering activities. Curiously, these implements are unique to the Schöningen Pleistocene deposits; to our knowledge, similar bone tools made from horse metapodials have not been reported from the Lower Palaeolithic, or other Middle and Upper Palaeolithic sites, for that matter. Damage to the metapodials is markedly different from the pits and scores observed on "classic" bone retouchers (i.e., limb bone shaft fragments), suggesting their use in a different set of tasks. Classic bone retouchers have been the subjects of numerous experimental and functional analyses (e.g., Vincent, 1993; Mallye et al., 2012; Tartar, 2012; Mozota, 2013; Daujeard et al., 2014), but experimental inquiry into the use of metapodials as tools is merely anecdotal. Moreover, the hypothesis relating the observed damage on the Schöningen metapodials to heavy-duty hammering activities (van Kolfschoten et al., 2015b) has never been tested experimentally.

Here we describe the complete collection of metapodials with battering damage from the Schöningen 13II-4 "Spear Horizon" and detail a series of preliminary experiments aimed to test if these bones are suitable for heavy-duty hammering activities and to better understand what function(s) they may have served for Middle Pleistocene hominins. Taking into account the complete archaeological context of these tools, we explore the overall suite of technological behaviours associated with the widespread use of bone tools at Schöningen.

Site background

The Schöningen 13II-4 "Spear Horizon" site represents one in a series of Middle Pleistocene localities excavated in an expansive open-cast lignite mine near the town of Schöningen in Lower Saxony, Germany, roughly 100 km east of Hannover (**Figure 2**). Research over the past several decades have generated volumes of geological, environmental, palaeontological, and archaeological data to contextualise these remarkable finds (e.g., Thieme, 2007; Behre, 2012; Conard et al., 2015).

Geologically, the Schöningen 13II site complex is situated within a tunnel valley formed during the Elsterian glaciation and features a series of laterally and vertically stacked lacustrine/deltaic sediment deposits (Lang et al., 2012; Lang et al., 2015). The local stratigraphic profile includes five sedimentary cycles corresponding to lake level shallowing events; the fourth cycle includes the main find-bearing layers (4a, 4b, 4b/4c, 4c) known as the "Spear Horizon". Recent efforts to date the site provided a maximum age of 337-300 ka (Marine Isotope Stage 9) based on the thermoluminescence signal of heated flints from the nearby archaeological site of 13I-1,

Figure 1 Representative battering damage to distal articular surface of metacarpal (10037). Scale bar = 5 cm.

which lies stratigraphically below the 13II-4 "Spear Horizon" (Richter and Krbetschek 2015).

Pollen indicators reflect both terrestrial and aquatic interglacial vegetation, dominated by open grassland interspersed with stands of pine *(Pinus* sp.) and birch *(Betula* sp.) (Urban and Bigga, 2015). The faunal is typical of the prevailing interglacial conditions, dominated by horse *(Equus mosbachensis)* and fewer bones of several bovid and cervid species, as well as a diversity of other large and small mammals, fish, birds, and amphibians (Voormolen, 2008; van Kolfschoten, 2012, 2014; van Kolfschoten et

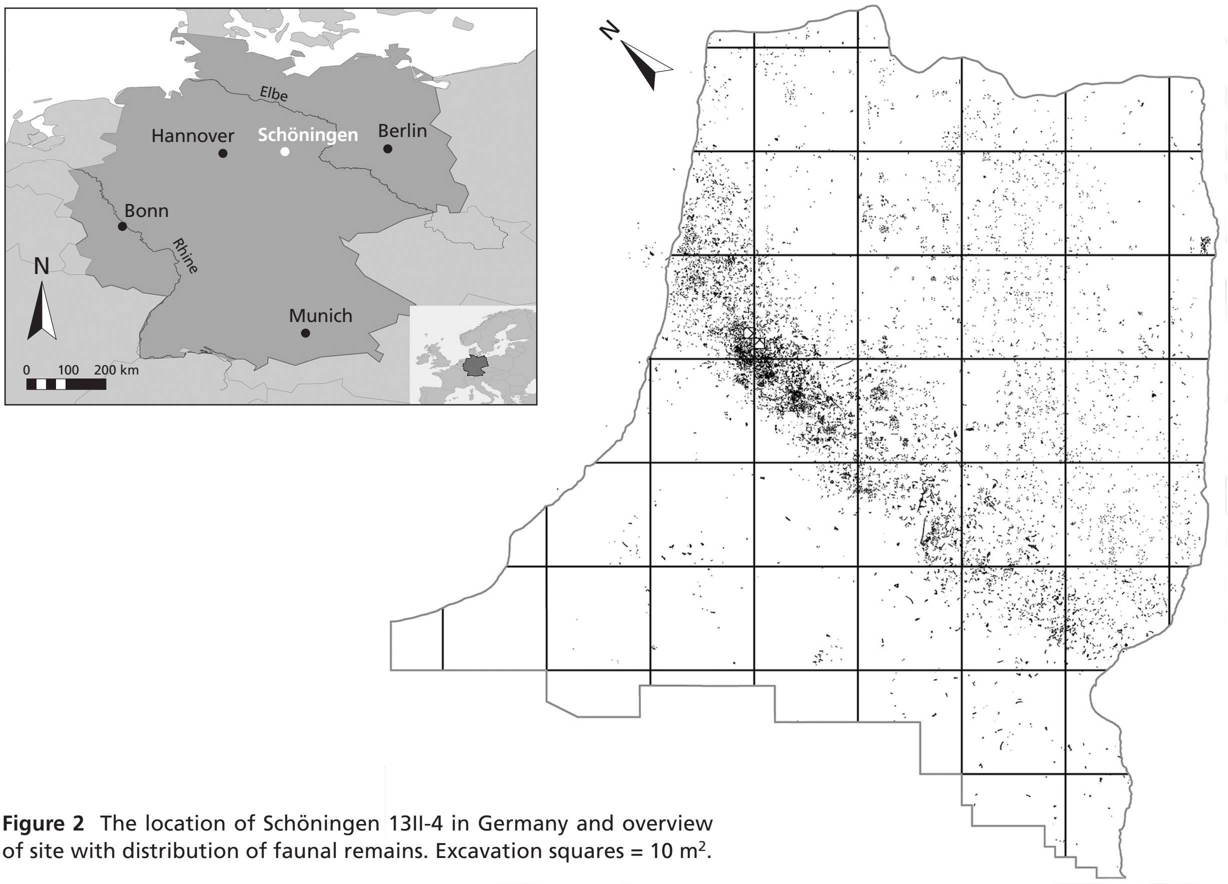

Figure 2 The location of Schöningen 13II-4 in Germany and overview of site with distribution of faunal remains. Excavation squares = 10 m².

al., 2015a). Most of the archaeological remains are concentrated in a ten-metre-wide band oriented north-to-south across the central portion of the excavation area (see Figure 2). This linear concentration likely corresponds to a former shoreline of the lake, with dry land to the west and the deeper part of the lake basin to the east (Böhner et al., 2015; Turner et al., in press). The more than 50 horse individuals represented in the complete assemblage are thought to represent the remains of multiple hunting and butchery episodes at or near the former lakeshore (Voormolen, 2008; van Kolfschoten et al., 2015a; Hutson et al., in press). The modest lithic assemblage, amounting to roughly 1500 artefacts, is made from local, high-quality flint and features intensely retouched and re-sharpened tools attributed to the late Lower Palaeolithic (Serangeli and Conard, 2015). Most of the lithic material is representative of a very expedient tool-kit, dominated by scrapers, small flakes, and retouch debris; large cores and hammerstones are almost entirely absent.

Framework for studying the Schöningen metapodial hammers

Due to the rarity of metapodial hammers in Palaeolithic assemblages of any age, their function has only been recently hinted at, and the previous interpretation of Schöningen metapodials used as hammers was not backed by any experimental trials (van Kolfschoten et al., 2015b). Without question, the degree of damage observed on most of these metapodials was generated by a considerable force against a hard object. The most likely target materials at Schöningen were stone and other bones, although wood is also a possibility.

Because no pieces of flint were found embedded in the proximal or distal ends of any previously studied metapodial hammer from Schöningen, van Kolfschoten et al. (2015b) considered it unlikely that stone working was the activity that produced the damage. The Schöningen 13II-4 deposit contains dozens of smaller limb bone shaft fragments that preserve the distinctive markings of use as retouchers, many of which include embedded flint. For the purpose of stone working, the proximal and distal ends of horse metapodials are not particularly suited for the delicate task of retouching the cutting edge of a lithic tool. If the metapodials were indeed used in lithic manufacture, a more likely scenario is that the observed damage relates to knapping activities that require a greater force, such as shaping, trimming, or the creation of flakes. These tasks may not leave traces of flint embedded in the bone, as with each successive blow the cortical surface of the bone erodes, taking with it any embedded flint. With regard to the Schöningen 13II-4 lithic assemblage, the presence of several thin flakes and chips with diffuse bulbs and lips demonstrates the use of soft hammer percussion (Serangeli and Conard, 2015), whereas other features indicate the use of hard (stone) hammers. Several metapodials reported by van Kolfschoten et al. (2015b) include both battering damage and retoucher use traces on the diaphyses; therefore, the metapodials could have served as multipurpose tools for various light and heavy-duty tasks within the lithic reduction sequence.

Citing the absence of large stones to serve as hammers or anvils in the Schöningen 13II-4 deposit, van Kolfschoten et al. (2015b) proposed that the metapodials were used to break open limb bones for marrow. This suggestion is bolstered by the lack of various impact features on the bones indicative of fracture using a hammerstone, namely percussion pits and microstriations associated with impact notches. Ethnographic observations of butchery activities and other experimental studies can also inform on the possibility of using metapodials for breaking other bones when hammerstones are not available.

Concerning the lack of large stones for breaking bones at Schöningen, Serangeli and Conard (2015) report nothing recognizable as a hammer or anvil, but Mania (1995:95) notes the presence of "some hammerstones of small quartz and quartzite pebbles" and "a large core" used as a chopping tool at Schöningen; however, it is unclear whether this is in reference to one of the archaeological layers at Schöningen 12 or 13. Nevertheless, it is safe to reckon that large hammerstones are exceedingly rare, or even absent, at Schöningen 13II-4. It is possible that hominins transported any large stones away from the site upon their departure. Many of the lithic cutting tools were likely brought to the site in finished form (Serangeli and Conard, 2015), so it is feasible that useable lithic materials, including hammerstones, would also be transported away from the site for use elsewhere on the landscape.

Based on observations of Nunamiut butchers breaking caribou *(Rangifer tarandus)* limb bones with other bones (report by Dan Witter in Binford, 1978:153-155), van Kolfschoten et al. (2015b) reasoned that the damage to the Schöningen metapodials is possibly the result of hammering activities to access marrow. Along a similar vein, Sadek-Kooros (1972) conducted a set of experiments that preliminarily tested the use of fresh bone to fracture lamb *(Ovis aries)* metatarsals. There was presumably some success with breaking lamb metatarsals with other fresh bones, but the details are not provided. In order to build a case for the use of bone tools at Makapansgat, South Africa, Dart (1959, 1961) enlisted Trevor Jones to replicate "cannon-bone scoops and daggers" by smashing through fresh metapodials with the articular ends of other metapodials. Making these tools required "an amount of planning, patience and persistence that is best appreciated by those who attempt to carry it out" (Dart, 1959:81), suggesting this was not an easy endeavour.

From these studies, it appears possible to break the limb bones of small and medium-sized ungulate limb bones with other bones of the same species, but there are several issues with analogizing these ethnographic and experimental accounts with the archaeological record at Schöningen. First, of 23 limb bones broken during the Nunamiut observations, only four were broken with other bones (Binford, 1978); the remainder were broken with the back of a metal hunting knife or a slender stone baton. It is clear that using bones to break other bones, albeit possible, was not the preferred method among Nunamiut butchers. Second, the limb bone portions used as hammers were the distal condyles of a femur and a head of a humerus. None of these bone portions from Schöningen show battering damage. Lastly, the caribou bones in the Nunamiut observations were substantially smaller and less robust than the horse *(Equus mosbachensis)* and bovid *(Bison* and *Bos)* limb bones from Schöningen. A healthy prime adult bull caribou mentioned in Binford's (1978:17) experiments weighed only 110 kg, and the lambs obtained from a commercial butcher by Sadek-Kooros (1972) likely weighed considerably less than 100 kg. Maximal estimated weight of *Equus mosbachensis* varies between 630 and 750 kg (Eisenmann, 2003:37), and mean body mass for Pleistocene *Bos primigenius* and *Bison priscus* is estimated at over 1000 kg (Saarinen et al., 2016:9). While bone density values are similar across different species of cervids, equids, and bovids (Lyman, 1984; Lam et al., 1999), the bones of larger species are thicker and presumably more difficult to break. In fact, Hadza butchers wielding axes, knifes, hammerstones, and anvils required increasingly more blows to break limb bones of progressively larger ungulate species (Oliver, 1993:213): the mean number of blows to break dik-dik *(Madoqua kirkii)* limb bones was 1.7, 7.1 blows for impala *(Aepyceros melampus)*, 9.9 for zebra *(Equus quagga)*, and 14.6 for buffalo *(Syncerus caffer)*.

Frison (1978) determined that bone implements were an important part of the butchery tool kit assemblages at prehistoric North American bison *(Bison bison)* kill sites. Detailed experiments revealed that femora and tibiae broken at an angle across their diaphyses to produce a "chopper" with a sharp point and a good handhold performed well, and even better than stone, at certain butchery activities, but were "worthless as a tool for breaking heavy long bone" (Frison, 1978:306). The manner in which these femora and tibiae were used in the context of bison kill sites is quite different than the proposed use of the Schöningen metapodials, but the difficulties encountered introduces an element of doubt regarding the possibility of breaking the robust limb bones of a bison with another bone. Dart (1959, 1961) was more successful in fracturing metapodials by means of using other bones, but breakage of sheep, goat, and ox metapodials occurred with some effort, after 30 to 140 blows from the articular ends of metapodials and the pointed distal ends of tibiae. However, Dart's (1959) stated intention was to reproduce a specific shape of break observed in several antelope metacarpals from the Makapansgat grey breccia, which calls into question the fidelity of the experiments.

With these concerns, we were sceptical from the onset that it would be possible to break a limb bone of a large ungulate with a metapodial from the same species. Nonetheless, a series of preliminary experiments were designed to test the performance of metapodials for breaking limb bones of large ungulates.

We began with the hypothesis that metapodials cannot be used to break limb bones of the same species. If the metapodial fractured or otherwise experienced failure, rendering it no longer functional as a hammer, prior to the fracture or failure of the target bone of the same species, then the hypothesis can be accepted. In consequence, the metapodials at Schöningen were not likely to have been used as hammers to break the limb bones identified in the faunal assemblage. Among the many alternative hypotheses are that the metapodials were used in the course of stone tool manufacture and maintenance, or the metapodials were struck against a hard object (stone or bone) with the intention of breaking the metapodial for access to the marrow inside.

Coming back to the original hypothesis, if the target bone fractured before the metapodial hammer, then the hypothesis can be rejected. Therefore, it is possible that the Schöningen metapodials were used as hammers to break limb bones. From this observation we can look to other features of the faunal assemblage to build a stronger case for the use of metapodials as hammers for breaking limb bones.

In concert with the bone breaking experiments, we also employed metapodials in various stone working tasks to determine their performance in creating lithic flakes from larger cobbles. These demonstrations were not designed to test a specific hypothesis, but aimed at seeking an alternative explanation for the damage on the metapodials if their use in breaking bones was rejected.

Materials and methods

Archaeological remains

The entire Schöningen 13II-4 "Spear Horizon" faunal assemblage, consisting of roughly 15,000 specimens, has been a subject of study by the MONREPOS Archaeological Research Centre and Museum for Human Behavioural Evolution since 2013. Portions of the assemblage have been previously described by Voormolen (2008) and van Kolfschoten et al. (2015a). For this study, each bone was individually examined and various taxonomic, anatomical, and taphonomic features were recorded in detail. Bone surface modifications were identified using a 10-20x hand lens and up to 40x digital microscopy when necessary. Metapodials were analysed with particular scrutiny, noting the previous observations of Voormolen (2008), van Kolfschoten et al. (2015b), and Julien et al. (2015) that highlighted the distinctive battering damage to the articular surfaces. All specimens displaying such damage were identified by species, skeletal element, and bone portion (proximal, distal, complete). Incomplete bones were classified into binned categories of 25% based on the percentage of remaining diaphysis. The location of the damage was documented as occurring at the proximal articulation or distal epiphysis, and the aspect was noted as medial or lateral. Two types of damage were documented: crushing and flaking. Crushing is defined as the attritional deformation of the articular surface through compression. Flaking takes the form of shallow to deep, arcuate to angular flake scars emanating from the articular margin. All ancient fractures were categorized as proximal, diaphyseal, or distal breaks, and fracture outlines were further identified as curved, longitudinal, or transverse relative to the long axis of the bone, following Villa and Mahieu (1991). These observations were intended to capture the variation in damage and bone breakage that may relate to the timing, intensity, and/or duration of use of the metapodials in percussive activities. Other traces of hominin butchery, modifications linked to flint-knapping, and carnivore damage were documented following accepted standards of identification (see Lyman, 1994; Fisher, 1995; Fernández-Jalvo and Andrews, 2016).

Experimental protocol

Experiments were designed to test the performance of metapodials in stone tool manufacture and breaking limb bones. It must be noted that these experimental trials should be considered as preliminary empirical tests for the use of metapodials in hammering activities, the results of which can serve as a foundation for further testing in a more rigorously controlled experimental programme. Here, our intentions were to determine the suitability of metapodials for stone working and bone breaking and to evaluate the types of damage produced. The damaged Schöningen metapodials have been previously discussed by van Kolfschoten et al. (2015b) as resulting from breaking bones for marrow, but this hypothesis has never been empirically tested, until now. Moreover, these experiments represent the first attempt to evaluate the performance of metapodials in stone working tasks and the resulting damage.

The first set of experiments involved a series of fresh, never-frozen, adult horse *(Equus caballus)* metapodials acquired from a commercial butcher; all were obtained already disarticulated from the upper limb. A period of one to two days elapsed between the slaughter of the animals and the experiments. The distal epiphyses were entirely fused on all horse metapodials, which established an age at death for the horse(s) to older than 15-20 months (Silver, 1963:252-253). The skin was removed, taking care to preserve the periosteum, the metapodials were disarticulated from the phalanges, and the various sinews were removed to expose the distal articular surfaces for use as hammers. If present, the adhering carpals, tarsals, and accessory metapodials were left in place.

The distal ends of two horse metapodials from the series were used in a fresh state to produce flakes from a Baltic flint core. During use, the metapodials were regularly checked for damage. Upon exhausting the core in one of the trials, the metapodial was swung against a large stone anvil until breakage occurred, a modified version of the percussion by "batting" technique described by Blasco et al. (2014). After use, any adhering tissues were removed from the metapodials, two holes were drilled into the shafts, and then the bones were dried in a low temperature oven to rid the bones of grease.

An additional two metapodials from the series were buried in loose sediment for a period of approximately six months, after which the proximal and distal ends were used in a semi-dry state to generate flint flakes. Both metapodials were swung against a large stone anvil after completion of the stone working tasks until breakage occurred.

For comparison, a sub-fossil metatarsal from a small *Equus* species (cf. *Equus hydruntinus)* was used to create flint flakes in order to assess damage created on bone with a significantly reduced organic fraction. The sub-fossil metatarsal was donated to the MONREPOS Archaeological Research Centre and Museum for Human Behavioural Evolution, along with a number of other unprovenienced specimens, by an amateur fossil collector.

For the second set of experiments, fresh *Bos taurus* metatarsals were obtained from a commercial butcher and used as hammers in an attempt to break open other fresh *Bos taurus* limb bones. Again, one to two days passed between slaughter and the experiments. The metatarsals were acquired already disarticulated from the rest of the limb. Further processing prior to the experiments included skinning, disarticulation from the phalanges, and removal of sinews to expose the distal articular surfaces. On the metapodials, the periosteum was preserved. The target limb bones were also disarticulated and stripped of all meat, but the periosteum was left intact. Some metapodial distal epiphyses were fused, while others were unfused, but held tightly to the metaphysis by a plate of epiphyseal cartilage. Fusion of distal metapodials typically occurs between two and three years of age (Silver, 1963:252-253), which is consistent with the age at which most beef cattle are killed, usually between 2.5 and 3.5 years. The target *Bos taurus* limb bones came from animals of a similar age.

Unfortunately, horse bones were not available for this phase of the experiments. We acknowledge that the morphology of bovid and equid metapodials is different, especially at the distal end, but we are confident that the performance of cattle metapodials in these experiments is equitable to that of horse metapodials based on their overall architectural similarities and comparable densities (see Lam et al., 1999; Ioannidou, 2003).

For each trial, each target limb bone was impacted with the distal end of a metapodial while resting on the ground or with a second limb bone serving as an anvil. With successive blows, the metapodial and target bone were inspected periodically to assess their integrity. The trial continued until complete failure of either the metapodial or target bone across the entire circumference of the shaft or through the distal epiphysis of the metapodial. The bones were gently simmered in water for approximately one hour with an enzyme-based detergent to remove any remaining meat and other tissues.

With the stone working and bone breaking experiments, damage to the proximal and distal ends of the metapodial and breakage characteristics of the shafts were recorded in the same manner as with the archaeological sample from Schöningen. Likewise, breakage features of the target bones were documented using standard zooarchaeological protocols.

The bone tool assemblage from Schöningen 13II-4

In our analysis of the complete faunal assemblage from the Schöningen 13II-4 "Spear Horizon," we identified 46 limb bones with crushing and flaking damage (**Table 1**). This total includes 14 horse *(Equus*

Figure 3 Horse metacarpal (1474) showing curved breaks across the disphysis and distal epiphysis. Scale bar = 5 cm.

mosbachensis) metapodials and one bison *(Bison priscus)* metacarpal previously reported by Voormolen (2008) and van Kolfschoten et al. (2015b). Much of the damage takes the form of crushing and flaking to the distal epiphyseal condyles of horse metapodials. On close inspection, these features are also prevalent on many proximal ends of metapodials. Several distal humeri also show similar battering damage. We documented three cervid *(Cervus elaphus)* distal metapodials with soft hammer damage and two further examples identified as bovid: one aurochs *(Bos primigenius)* metacarpal and one bison *(Bison priscus)* metatarsal. Because crushing and flaking damage is most prevalent on horse metapodials at Schöningen, further discussions will focus on evaluating the damage to those elements of the assemblage.

Horse metapodials

A total of 37 horse metapodials include crushing and flaking damage to the proximal and distal ends: 11 metacarpals, 24 metatarsals, and two indeterminate metapodial. From the entire sample of metapodial hammers, all are adult bones with fused distal epiphyses, except for one metacarpal (2881+4221) represented by a conjoining metaphysis and diaphysis pair that is not completely fused.

Crushing damage is present on the distal ends of all metacarpal hammers in the assemblage; thus, such damage can be considered a defining characteristic of metapodial soft hammers, in general. Flaking damage on the distal epiphyses is common, but not universal. Moreover, flaking damage always occurs in tandem with crushing. Only one

Table 1 Inventory of metapodials and other limb bones with damage interpreted as resulting from use as soft hammers. ID numbers shown in bold have been reported previously (van Kolfschoten et al. 2015b). Portion: D+S= distal+shaft; P+S = proximal+shaft. Damage: C = crushing, F = flaking.

						Damage			Breakage		
ID number	Square	Level	Side	Portion	Retouch	Proximal	Distal		Proximal	Diaphysis	Distal
							Lateral	Medial			
EQUID											
Metacarpal											
1474	684 / 27	4b / 4c	L	D+S (26-50%)	no			C		curved	curved
1648	684 / 29	4b	L	D+S (0-25%)	no			C		transverse	
2451	686 / 22	4b / 4c	L	P+S (26-50%)	yes	C				curved	
2881+4221	687 / 18+689 / 19	4b	L	D+S (26-50%)	no		C	C		curved	
4314	689 / 20	4b / 4c	L	Complete	yes		C	C			
6840	695 / 11	4a / 4b	L	Medial	yes		C, F	C	longitudinal	longitudinal	
7785	699 / 4	4b	R	Complete	yes		C	C			
9900	709 / 40	4b / 4c	R	D+S (0-25%)	no		C, F	C, F		curved	
10159+10162	711 / 6	4a	R	D+S (0-25%)	no		C			curved	longitudinal
10765	715 / 41	4c	R	Complete	yes			C, F			
15015	728 / -997	4b / 4c	R	D+S (0-25%)	no		C, F	C, F		transverse	
Metatarsal											
1495	684 / 27	4b / 4c	R	D+S (0-25%)	no		C, F	C, F		curved	
1541	684 / 28	4b	L	Proximal	no	C			curved		
3064	687 / 24	4b	R	P+S (26-50%)	yes	C, F			longitudinal	curved	
4292	689 / 19	4b	L	D+S (26-50%)	yes		C, F	C, F		transverse	
4552	689 / 26	4c	L	D+S (0-25%)	no		C, F	C, F		curved	
4564	689 / 26	4b	L	D+S (0-25%)	no		C, F	C, F		curved	
4743	690 / 18	4b	L	D+S (26-50%)	yes		C	C, F		curved	
5558.1	691 / 29	4b	R	P+S (51-75%)	no	C			longitudinal	curved	
5560+5561	691 / 29	4b / 4c	L	D+S (26-50%)	no		C, F	C, F		curved	curved
5636	691 / 40	4b	L	P+S (26-50%)	no	C, F			longitudinal	curved	
5719	692 / 15	4b / 4c	L	D+S (0-25%)	no		C, F	C, F		transverse	
6180	693 / 17	4b	R	D+S (0-25%)	no			C		curved	
6239	693 / 19	4b	R	P+S (0-25%)	no	C			transverse		

6734	694 / 20	4b	L	P+S (26-50%)	no	C, F			transverse	curved	
6866	695 / 12	4b	R	P+S (0-25%)	no	C			longitudinal		
7429	697 / 17	4b	R	D+S (0-25%)	no		C	C		curved	
8060	700 / 7	4b	L	P+S (26-50%)	yes	C, F			longitudinal	curved	
9068	705 / 1	4b	R	D+S (0-25%)	yes		C, F	C, F		transverse	
9157	706 / 1	4b	R	P+S (0-25%)	no	C			transverse	curved	
9193	706 / 16	4b / 4c	R	P+S (0-25%)	no	C				curved	
9529	707 / 34	4b	R	P+S (0-25%)	no	C, F				curved	
10037	710 / 9	4b	R	D+S (26-50%)	no		C	C, F		curved	
15577	721 / -978	4b	R	D+S (26-50%)	no		C	C, F		curved	
20760	706 / 9		L	P+S (0-25%)	no	C			longitudinal	curved	
Metapodial											
8879	703 / 5	4b	L	Distal	no					curved	
19782	713 / 18	4b / 4c	I	D+S (0-25%)	no		C, F		curved	transverse	
Humerus											
1842	684 / 32	4c	L	D+S (26-50%)	no		C	C, F		curved	longitudinal
3357 + 3358	687 / 45	4b	R	D+S (26-50%)	yes			C		curved	
7118	696 / 13	4b	L	D+S (26-50%)	yes		C	C		transverse	
CERVID											
Metacarpal											
8872	703 / 44	4b / 4c	L	D+S (26-50%)	no			C, F		curved	
18642.7	700 / 70 (arbitrary)	Abraumberg	R	D+S (0-25%)	no		C			curved	
Metapodial											
12860	717 / -996	4b	I	Distal	no		C, F				
BOS											
Metacarpal											
1229	683 / 30	4b / 4c	R	Complete	no		C	C			
BISON											
Metacarpal											
1259	683 / 30	4a / 4b	L	Complete	yes	C	C	C			
Metatarsal											
7720	699 / 16		L	Complete	yes		C	C			

Figure 4 Horse metacarpal (6840) with longitudinal break along the diaphysis and extending through the proximal epiphysis. The anterior shaft preserves traces of retouching activities and the distal articular condyles show crushing and flaking damage. Scale bar = 5 cm.

Figure 5 Horse metatarsal (9157) with crushing damage to proximal epiphysis. Scale bar = 5 cm.

specimen (2451) displays crushing damage to the proximal end. Elements from the right and left sides are equally represented, and there is no preference shown for either the medial or lateral condyle on the distal end. Seven of ten metacarpals that include the complete distal end show damage to both condyles.

In terms of breakage, all metacarpal hammers with only the proximal or distal end preserved include less than half of the original length of the diaphysis. Many preserve only a quarter of the original length. Transverse breaks across the diaphysis occur only on specimens preserving 0-25% of the original shaft length, although there are some examples of curved breaks on these shorter specimens. The longer specimens, with 26-50% of original metacarpal length, preserve only curved breaks on the diaphysis. Specimen 1474 displays a second curved break across the distal end (**Figure 3**), where nearly the entire distal epiphysis has been detached from the remaining portion of the diaphysis. There are three complete metacarpals with soft hammer damage, and one specimen (6840) that includes an unusual longitudinal break extending from the distal metaphysis to the proximal end, so that the distal epiphysis is complete, but only the lateral portions of the diaphysis and proximal articulation are preserved (**Figure 4**).

It is interesting to note that all complete metacarpals with soft hammer damage and the specimen with the longitudinal break also include long striations on the anterior face underlying extensive damage related to stone working (see **Figure 4**). The numerous pits and scores on these specimens appear similar to marks created through retouch-

Figure 6 Horse metatarsal (5558.1) preserving more than 50% of the original shaft length and showing crushing damage to proximal end. Scale bar = 5 cm

ing activities (e.g., Patou-Mathis, 2002; Mallye et al., 2012). The proximal metacarpal specimen also shows similar striations and stone working damage to the anterior shaft. In this case, as with the specimen with the longitudinal break, the striations, pits, and scores are abruptly truncated by the fracture. We suspect the crushing damage to the proximal ends led to breakage of the shaft; moreover, the crushing damage likely followed or was penecontemporaneous with the damage to the diaphysis related to stone working. Clearly, these metacarpals had longer and more complex taphonomic histories than their individual functions as soft hammers or stone working tools.

The metatarsals used as soft hammers show similar types of damage as the metacarpal sample. Of the 24 metatarsals, 12 proximal ends and 12 distal ends show crushing and flaking damage. As with the metacarpals, crushing damage is present on all metatarsal hammers (except 8879, discussed below). Flaking damage is considerably more prevalent on the distal metatarsals than on the metacarpals, with ten of 12 distal ends showing flake scars on the condyles. Crushing damage to the proximal ends is more common on the metatarsals than metacarpals (Figure 5). Some proximal ends also show some flaking damage, albeit considerably less invasive than on the distal ends. As with the metacarpals, bones from the left or right side of the body were used as hammers in relatively equal proportions; similarly, there is no preference shown for either distal articular condyle. In fact, of the specimens preserving both condyles, all but one (6180) shows damage to both medial and lateral condyles.

The dimensions of the metatarsal hammers are equally divided between 0-25% and 25-50% of their original length. Only one specimen (5558.1; Figure 6) with a shaft length beyond 50% was documented among the metatarsals, and no complete horse metatarsals with hammer damage were

Figure 7 Horse metatarsal (5560 + 5561) with dual break across diaphysis and distal epiphysis. Scale bar = 5 cm.

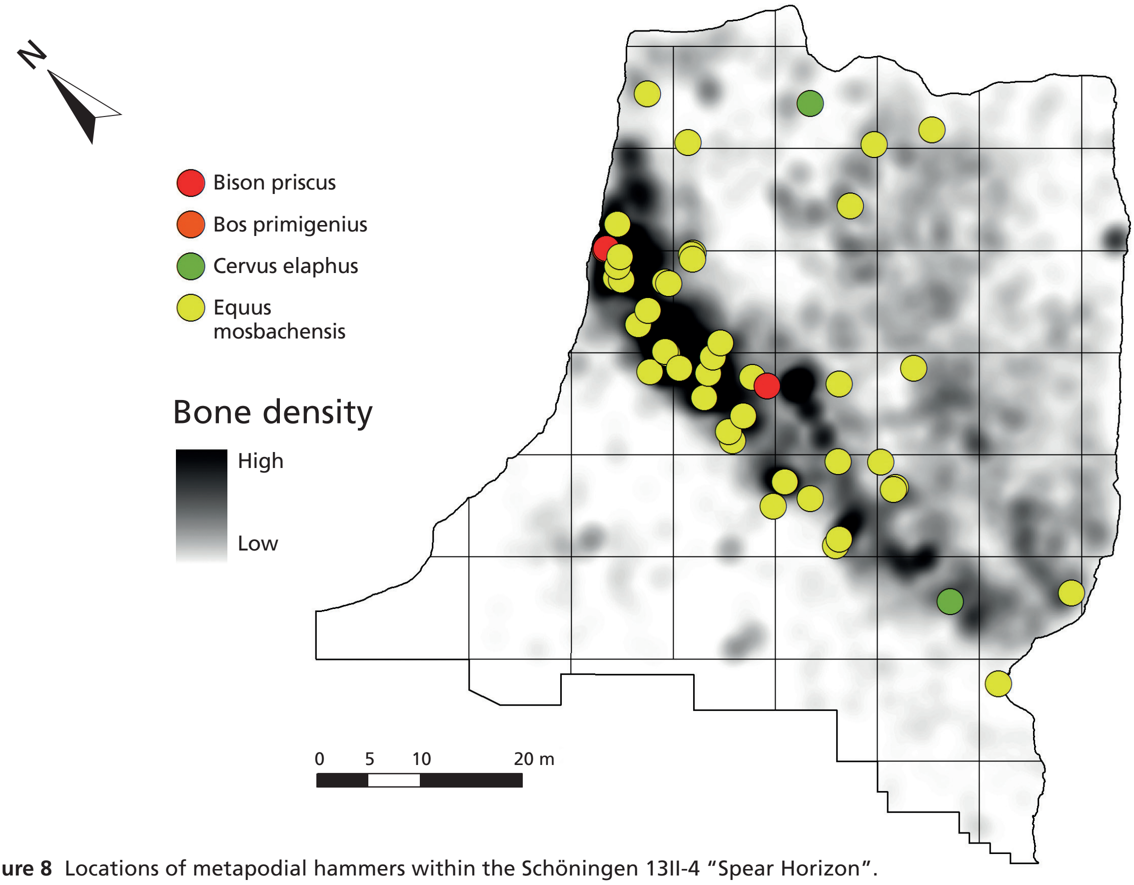

Figure 8 Locations of metapodial hammers within the Schöningen 13II-4 "Spear Horizon".

recorded. Proximal breakage outlines are mostly longitudinal through the articular surface, followed by transverse outlines across the metaphysis, and a solitary example was recorded with a curved breakage outline. Breaks across the diaphysis are dominated by curved outlines; three show transverse outlines. One notable specimen comprises a conjoining pair of bones (5560+5561; **Figure 7**), with a dual diaphyseal and distal break, reminiscent of the breakage pattern in specimen 1474 discussed above. The curved break across the diaphysis is coupled with a second curved break through the distal epiphysis where the two bones refit.

Five of the metatarsal specimens also preserve pits and scores on the diaphysis consistent with marks from retouching activities, some of which measure among the longest of specimens in the sample. Though broken, these specimens show affinities to the complete metacarpals, with extensive longitudinal striations paired with pits and scores indicative of stone working activities.

Two bones could only be identified as metapodials (see **Table 1**). Specimen 8879 includes only a small, broken piece of the distal epiphysis with the same breakage morphology as specimen 5561 (see **Figure 7**). However, the conjoining portion of the diaphysis has not been identified and there is no crushing or flaking damage to the remaining portion of the distal epiphysis. The other metapodial specimen (19782) shows crushing and flaking to the remaining portion of epiphysis and similar breakage features to the other metapodials in the assemblage. The irregular, transverse break through the distal epiphysis is likely postdepositional.

The spatial arrangement of metapodial soft hammers identified as horse mirrors the overall distribution of bones in the "Spear Horizon" (**Figure 8**). Most are located along the nearly 10 m x 40 m main artefact concentration at the site. This arrangement likely reflects some aspect of the relict shoreline during the Middle Pleistocene occupation of the site, where much of the butchery activities took place. This is made clear by the distribution of hominin-modified bones and lithic debris along the same concentration. A few metapodial tools lie further to the east in the part of the site judged to have been toward the deeper part of the lake basin. These stray finds in the lower density areas may represent different hunting and butchery episodes during times when the lake level was lower.

Horse humeri

In addition to the metapodials with soft hammer damage, three horse humeri show crushing of the distal articular condyles along the margin of the trochlea (see **Table 1**). Although the damage is similar to that shown on metapodials (**Figure 9**), crushing damage on distal humeri is comparatively rare; thus, it is unclear whether this can be attributed to the use of distal humeri as tools or some other pre- or postdepositional processes.

Two of the three humeri show traces of use in retouching activities, which does confirm their use as tools in some capacity. One of these specimens is a refit pair (3357+3358; **Figure 10**), comprising a distal humerus-plus-shaft with a conjoining portion of the medial shaft. Together, these specimens display a complex modification sequence. Striations oriented parallel to the long axis of the bone extend across both bone specimens. Lightly-incised marks consistent with retouching activities occur together with striations near the proximal break on the large distal-plus-shaft specimen (3358); these marks do not extend onto the medial shaft specimen (3357). There are multiple negative flake scars from impact on the interior bone wall of the shaft fragment, but no visible impact point on the exterior surface. The

Figure 9 Horse humerus (1842) with crushing damage to the distal epiphysis. Scale bar = 5 cm.

Figure 10 Horse humerus (3358) with crushing damage to the distal epiphysis. Scale bar = 5 cm. Note: conjoining shaft fragment (3357) with pits and scores from retouching not shown.

sequence of damage appears to have proceeded from the striations and retouch damage to breakage from impact. The possible use of the distal end as a soft hammer could have occurred at any time during the sequence.

Specimen 7118 has damage from retouching activities in the same location on the medial shaft, but with no associated striations. At the proximal break there are two negative flake scars on the interior bone wall positioned on the medial and lateral sides, representing impact and rebound points resulting from the use of an anvil. It may be the case that these two humerus specimens with possible soft hammer damage and marks from retouching activities were complete during most of their use lives, much like the complete metatarsal specimens with similar features.

The humerus of a European saber-toothed cat *(Homotherium latidens)* from the Schöningen 13II-4 "Spear Horizon" also shows striations, marks from retouching activities, and damage to the distal epiphyses (Serangeli et al. 2015; van Kolfschoten et al., 2015b). This specimen was not available for detailed study here, but the damage to the distal epiphysis has been interpreted as manipulation by carnivores. Based on the available images of the specimen and limited first-hand observation, we argue the damage is not related to carnivore gnawing, but rather the crushed or eroded area on the distal epiphysis may be the result of use as a soft hammer. Scraping marks overlie weathering cracks and exfolilated surfaces, suggesting that the *Homotherium* humerus was used in a lightly weathered state (Serangeli et al. 2015; van Kolfschoten et al., 2015b), which may have resulted in the atypical pattern of damage to the distal epiphysis.

Cervid metapodials

Only three cervid metapodials include crushing and flaking damage to the distal epiphyses (see **Table 1**). The crushing and flaking damage to the dis-

Figure 11 Red deer metapodials (8872, left; 12680, right) with light crushing damage to the epiphyses. Scale bar = 5 cm.

tal epiphysis of specimen 8872 (**Figure 11**) is less invasive than on the horse specimens, but significant enough to be considered as resulting from the same activities. Also included among the cervid metapodial hammers is an unfused distal condyle (12680) from an indeterminate metapodial with light damage to the articular margin (see **Figure 11**). We included specimen 18642.7 despite its insecure attribution to the "Spear Horizon". The specimen comes from unprovenienced overburden (Abraumberg) sediment, but the damage compares well with other specimens from the "Spear Horizon" levels.

As for the distribution of cervid metapodial hammers, they are located away from the main concentration and are not associated with the large assemblage of butchered horse bones (see **Figure 8**). However, they are situated in the vicinity of dense concentrations of other cervid remains and were likely used during the butchery process of an individual animal killed on site.

Bovid metapodials

Like cervids, bovid bones are less abundant than horse remains at the site, and soft hammer damage has been recorded on only three metapodial specimens (see **Table 1**), all of which are complete bones. Two metacarpals show heavily worn distal articular condyles: specimen 1229 (**Figure 12**) is an aurochs *(Bos primigenius)* and specimen 1259 (**Figure 13**) is from a bison *(Bison priscus)*. Additionally, the bison metacarpal also displays crushing damage to the proximal end and extensive striations, pits, and scores on the anterior face of the diaphysis. A bison metatarsal (7720; **Figure 14**) shows crushing of the distal articular surfaces and striations associated with dense fields of pits and scores from stone working. Several areas on this metatarsal are scaled, where bony plates have become detached from the surface, suggesting this bone was used, at least for some time, in a degreased or dry state. Overall, these complete bovid

Figure 12 Aurochs metacarpal (1229) with crushing damage to the distal epiphysis. Scale bar = 5 cm.

bones show very similar patterns of damage as the complete horse metacarpals, and were likely used for the same purpose(s).

In terms of distribution, the bovid metapodial hammers are located within the main concentration and among other bovid bones with butchery marks (see **Figure 8**). Specimens 1229 *(Bos primigenius)* and 1259 *(Bison priscus)* were recovered from the same one-metre excavation square toward the north end of the main concentration. This peculiar arrangement may suggest that these bones were gathered from existing carcass remains at the site or were carried to the site from the surrounding landscape by hominins.

Experimental results

As mentioned previously, features of the Schöningen 13II-4 "Spear Horizon" lithic assemblage indicate some elements of both soft and hard hammer percussion (Serangeli and Conard, 2015). This argument is supported by the identification of dozens of limb shaft fragments bearing the tell-tale pits and scores of stone working activities (Voormolen, 2008; van Kolfschoten et al., 2015b). On the other hand, the lack of several distinctive hammerstone percussion features (percussion pits and microstriations) on the intentionally fractured limb bones and absence of large hammerstones in the Schöningen 13-4 "Spear Horizon" deposit is taken as evidence that the crushing and flaking of the distal ends of the metapodials was the result of breaking bones for marrow extraction (van Kolfschoten et al., 2015b). To evaluate these claims, we designed a series of experiments to evaluate the performance of metapodials in stone working and bone breaking tasks.

Stone working experiments

In all trials, the horse metapodials performed well as soft hammers for striking simple flakes from a flint core. With fresh bone, crushing damage to the distal epiphyses was quickly produced after a few

Figure 13 Bison metacarpal (1259) with heavy crushing damage to the distal epiphysis, crushing damage to the proximal epiphysis, and pits and scores on the diaphysis from retouching activities. Scale bar = 5 cm.

Figure 14 Bison metatarsal (7720) with heavy crushing damage to the distal epiphysis and pits and scores on the diaphysis from retouching activities. Scale bar = 5 cm.

blows against the flint (**Figure 15**). Flaking of the distal epiphysis did not occur with such ease during flint knapping activities. We are under the impression that flaking is produced with substantially higher force than required for crushing damage to occur; however, we stress that the angle at which the bone is struck against the flint and the duration of use likely play important roles in the resulting damage. Flaking damage (**Figure 16**) was only produced when swinging the metapodial against a large flint anvil with great force. Likewise, breakage of the metapodial did not occur during the course of producing flakes. It does not appear that the low-impact forces or fatigue from multiple low-impact blows are sufficient to cause bone breakage. Only when the intent was to break the metapodial were we able to produce a fracture (see **Figure 16**) consistent with that seen in the Schöningen assemblage. We contend that the amount of force required to break a metapodial through the shaft or across the epiphysis far exceeds that produced during retouching activities and likely beyond that of most flake-producing tasks. However, under the right conditions, perhaps using a substantially defatted or dry metapodial and with sustained use, breakage of the metapodial could occur during the production of lithic flakes. Accordingly, we argue that the Schöningen metapodial hammers were wielded with such force that the breakage was either intentional or, at least, there was an awareness that these implements could break during use.

For the dry bone trials, crushing damage was produced with little effort on the distal ends (**Figures 17 & 18**), appearing no different than on fresh bone. Again, flaking damage only occurred with great force, beyond that normally generated during most knapping activities. When present, flaking damage on dry bone appeared more angular than on fresh bone (see **Figures 17 & 18**), although this is based on very small sample. Crushing and flaking was

Figure 15 Crushing damage to fresh horse distal metapodial resulting from experimental stone working. Scale bar = 5 cm.

Figure 16 Flaking damage to fresh horse distal metapodial and breakage through the distal epiphysis resulting from experimental stone working. Scale bar = 5 cm.

also produced on proximal ends (see **Figure 18**). It should be noted that the damage on the proximal ends of the Schöningen metapodials encroaches on the articular surfaces of some bones (see **Figures 5 & 13**), which would have required the removal of the carpal/tarsal mass and sinews that hold the joints together. With a fresh carcass, all of this is possible with a sharp cutting edge, but the process was simplified for our experiments through burial of the metapodials and natural decay of any adhering tissues. With the removal of the carpal mass, the broad, proximal ends of the metacarpals provided a large working area that created a lot of shatter when struck against the flint, some of which became embedded in the surface of the bone (see **Figure 17**). None of the Schöningen specimens have embedded flint related to soft hammer damage on the proximal or distal ends. In terms of breakage, again it was the case that fracture occurred only when the metacarpals were intentionally struck against a large

Figure 17 Crushing and flaking damage to dry horse distal metapodial resulting from experimental stone working. Arrow marks small piece of flint embedded in the bone. Scale bar = 5 cm

flint anvil. One metacarpal struck with its distal end displays a transverse fracture just above the epiphysis (see **Figure 18**), while the other metacarpal was struck against the flint cobble with its proximal end and shows a curved break across the diaphysis (see **Figure 17**). Despite its dry appearance, this bone retained enough bone grease or marrow to break in a manner more consistent with fresh bone.

During the last trial involving a subfossil metatarsal (cf. *Equus hydruntinus)*, flaking on the distal epiphysis was easily produced with minimal force (**Figure 19**), and a transverse break was generated across the shaft after only a few blows. The flaking is somewhat angular and does not penetrate deeply into the bone. Furthermore, flaking occurred without the appearance of crushing damage to the epiphysis, likely because the bone was relatively brittle and inelastic.

Bone breaking experiments

Results of the seven trials of breaking limb bones with the distal ends of metapodials are outlined in **Table 2**. Three of the seven trials resulted in the breakage of the target limb bone; the metapodials failed prior to the target bone in the four remaining trials. These experiments were conducted under the hypothesis that metapodials cannot be used to break limb bones. Based on the results, this hypothesis is preliminarily rejected. Thus, it is possible that the Schöningen metapodials were used to break limb bones. Additional experimental trials across a

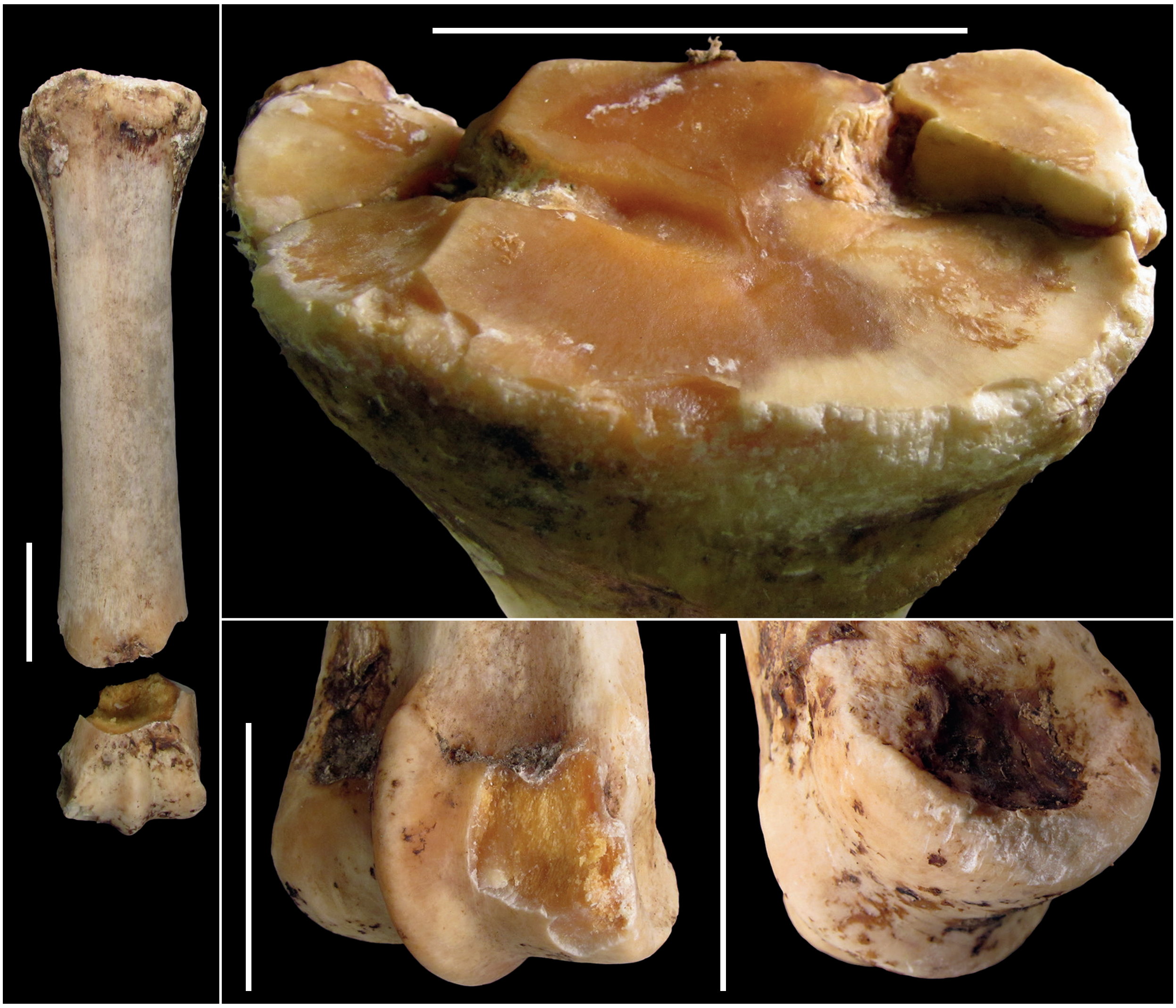

Figure 18 Crushing and flaking damage to dry horse proximal and distal metapodial resulting from experimental stone working. Scale bar = 5 cm.

Figure 19 Flaking damage to distal epiphysis of small equid species metapodial resulting from experimental stone working. Scale bar = 5 cm.

Table 2 Results of bone breaking experiments. (-) indicates condyle not used to impact target bone; (none) indicates condyle was used to impact target bone but no damage was observed. Damage: C = crushing, F = flaking.

				Damage to Metatarsals			
				Distal		Breakage	
Trial #	Target bone	# Blows	Broken bone	Lateral	Medial	Diaphysis	Epiphysis
1	Tibia	53	Target	none	-		
2	Femur	5	Target	-	none		
3	Radio-ulna	14	Metatarsal	none	-	curved	
4	Humerus	22	Metatarsal	F	-	curved	
5	Radio-ulna	33	Metatarsal	none	-	curved	
6[a]	Humerus	8	Target	-	C		
7[b,c]	Radio-ulna	44 + 32	Metatarsal	C, F	C, F	curved	oblique

[a] metatarsal reused from trial 1, [b] metatarsal reused from trial 2, [c] radio-ulna reused from trial 3

range of large ungulate species, including horse, are necessary to confirm that breaking limb bones in this manner is possible in cases beyond the relatively young cattle bones used here.

In the trials resulting in breakage of the target bone, the tibia (trial 1; **Figure 20**) fractured after 53 heavy blows from the metatarsal hammer. In contrast, the femur (trial 2; **Figure 21**) and a humerus (trial 6; **Figure 22**) broke with relative ease, requiring only five and eight blows, respectively. It should be noted that the same metatarsal was used in trials 1 and 6. This lends support for the durability of the metapodial hammers and their potential use in breaking numerous limb bones during a single or multiple butchery episodes.

Concerning damage to the target limb bones, there were no visible percussion pits or striations indicting the bones were struck with a hammer, but a single negative flake scar was noted on the interior wall of the femur shaft from trial 2 (see **Figure 21**). During trial 6, a tibia was used as an anvil to elevate the proximal end of the humerus off the ground, and one of the resulting humerus shaft fragments includes two negative flake scars (see **Figure 22**), one resulting from direct impact by the metatarsal and the other likely representing a counterblow from the tibia anvil. There were no indications of percussion on the tibia in trial 1 other than the hackle marks on the fracture surface caused by dynamic loading (see **Figure 20**).

As an aside, none of the target limb bone surfaces were prepared by removing the periosteum, which could have inhibited the production of marks on the bone surfaces. However, it was noticed that within the first few blows with the metatarsal, the periosteum began to tear away from the bone (**Figure 23**), exposing the surface to subsequent blows. Therefore, we conclude that the periosteum did not play a role in the absence of the surface damage to the target limb bones. This revelation has implications for the long-held notion that "the secret to controlled breakage of marrow bones is the removal of the periosteum in the area to be impacted" (Binford, 1981:134). Our experiments show removal of the periosteum can be achieved with blows from a metapodial hammer, and does not necessarily require the use of a sharp stone tool. Both methods produce similar results, but blows from a metapodial leave no traces of bone preparation, whereas stone tools will invariably leave elongated striations oriented parallel to the long axis of the bone. These striations do occur on many of the Schöningen 13II-4 limb bone fragments, but their presence may be related to preparation of the surfaces for stone working activities rather than for bone breakage for marrow.

The damage produced to the distal condyles of the metatarsals during these trials was minimal. Despite the high number of blows delivered by the metatarsal in trial 1, no damage was observed on

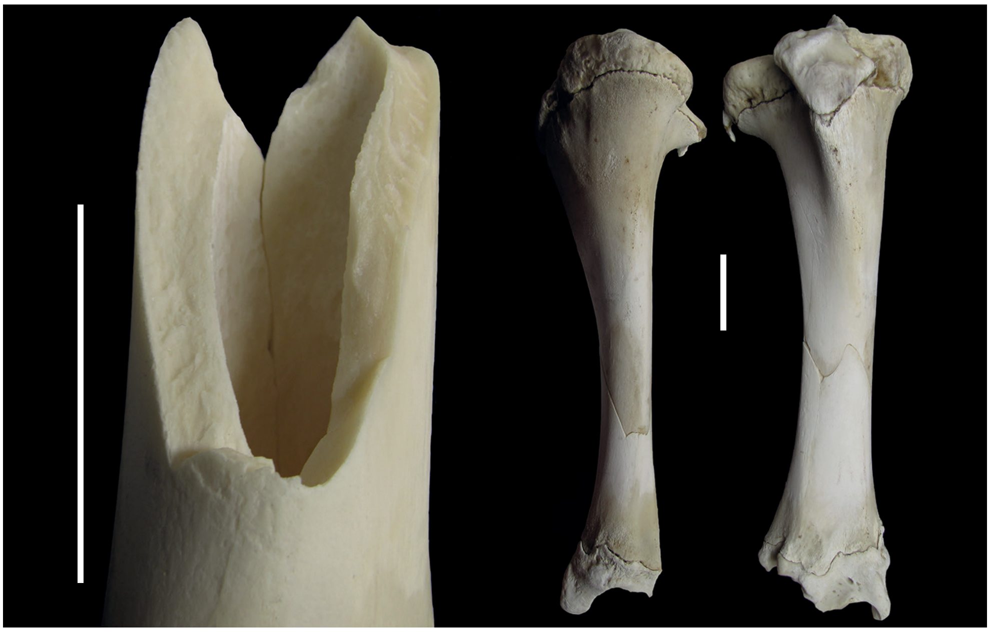

Figure 20 *Bos taurus* tibia experimentally broken with *Bos taurus* metapodial; breakage surfaces shows hackle marks indicating dynamic fracture. Scale bar = 5 cm.

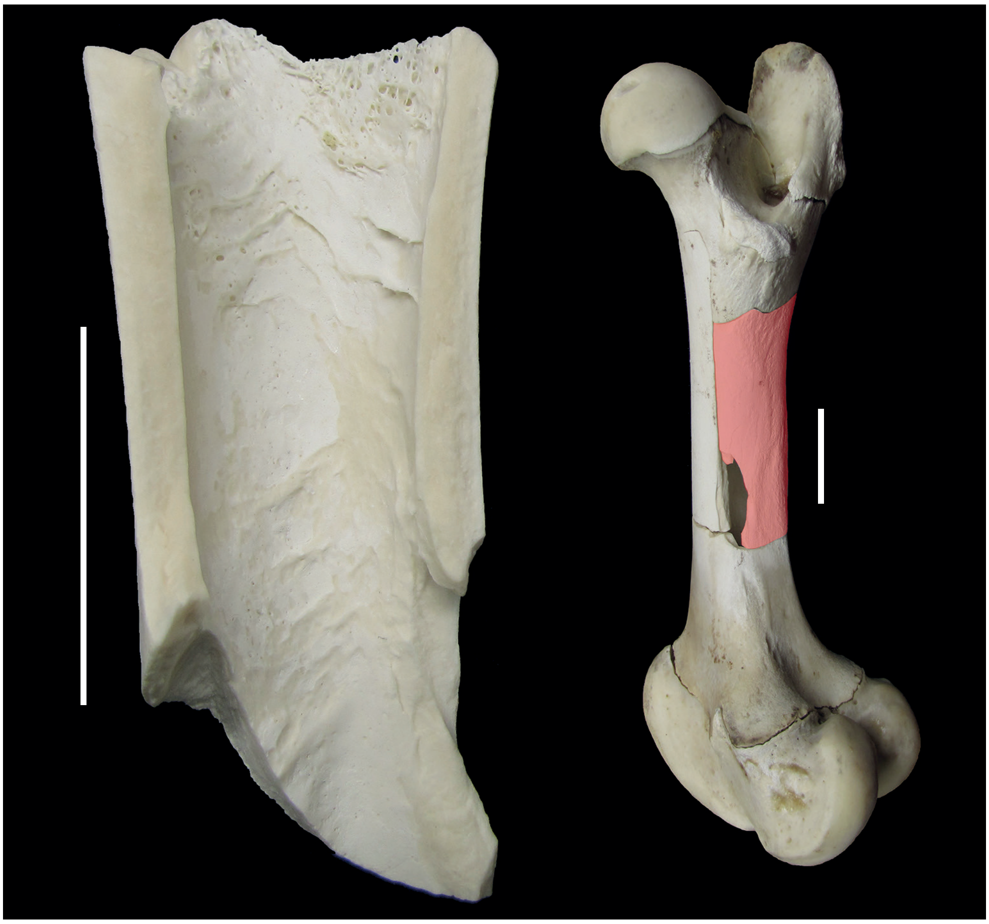

Figure 21 *Bos taurus* femur experimentally broken with *Bos taurus* metapodial; interior surface of shaded shaft fragment includes irregular impact notch. Scale bar = 5 cm.

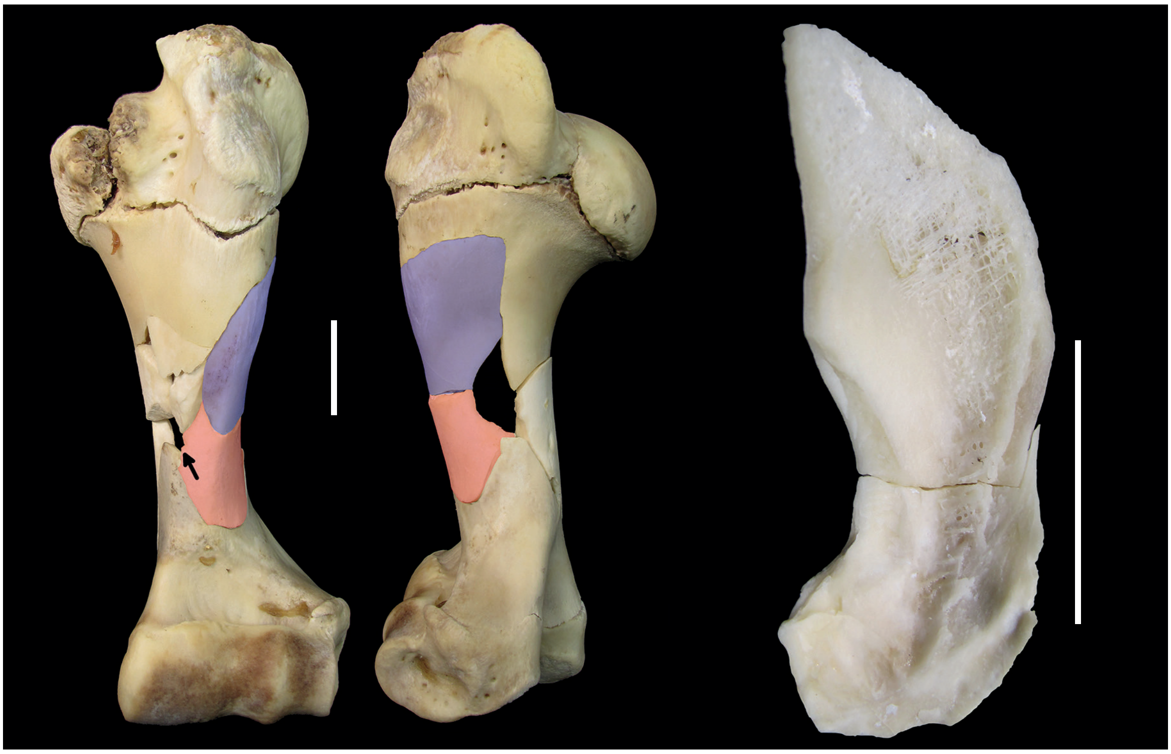

Figure 22 *Bos taurus* humerus experimentally broken with *Bos taurus* metapodial. Arrow denotes location of impact; interior surface of shaded limb fragments preserve impact notch and second counterblow notch. Scale bar = 5 cm.

the lateral condyle. Likewise, five blows produced no damage on the medial condyle of the metatarsal used in trial 2. Three blows into trial 6, light crushing damage appeared on the medial condyle of the metatarsal (**Figure 24**). We do not expect a random development of damage to the distal condyles, but rather crushing, followed by flaking, is likely the result of impact beyond a certain force threshold delivered at a particular angle, the exact parameters of which cannot be so precisely determined with the limited number of experimental trials conducted for this study. Nevertheless, it is noteworthy that 53 hammer blows broke the intended target bone in trial 1, yet no observable damage was produced. This has obvious consequences for the ability to recognize such tools and associated behaviours in the archaeological record at Schöningen and other Palaeolithic localities.

In four of the trials, the metatarsal broke prior to the target bone. This does not detract from the results where the target bone was broken first, but does highlight the varying degrees of success with this method of breaking bones. However, failure to break the target bone in these trials likely had as much to do with inexperience using this particular technique rather than the inability of metapodials to successfully perform the task at hand. For example, trial 4 resulted in the failure of the metatarsal after 22 blows against a humerus mid-shaft, just below the teres major tubercle. In trial 6, the blows were targeted more toward the proximal end, adjacent to the teres major tubercle on the medial side (see **Figure 22**), and the humerus fractured after only eight blows. Just as with a hammerstone, the location of the blows is critical to the successful fracture of the target bone, a process that must be learned through trial and error by a novice experimenter, but a convention likely well known to Middle Pleistocene hominins seeking access to marrow.

Trials 3, 5, and 7 enlisted a radio-ulna as the target bone, and in all trials the metatarsal broke first. The radio-ulnae were struck on the anterior face toward the proximal end along the medial margin, locations with numerous impact marks in the Schöningen

Figure 23 Periosteum pulling away from *Bos taurus* limb shaft during bone breaking experiments.

13II-4 assemblage. In trials 3 and 5, the metatarsal broke after 14 and 22 blows, respectively. The medial condyle of the metatarsal used in trial 7 failed after 32 blows and the trial was terminated after a further 44 blows to the lateral condyle. In trial 7, a complete tibia was used as an anvil to elevate the proximal portion of the radio-ulna off the ground, but this technique proved ineffective. In the end none of the radio-ulnae were broken; obviously the location in which the radio-ulnae was struck needs to be reconsidered in any future experiments.

Damage produced in these trials is clearly mirrored in the Schöningen 13II-4 "Spear Horizon" metapodial assemblage, both on the distal condyles and in the patterns of breakage across the shaft or distal epiphysis. **Figure 25** shows crushing and flak-

Figure 24 Light crushing damage to *Bos taurus* distal metapodial resulting from bone breaking experimental trial 6. Scale bar = 5 cm.

Figure 25 Crushing and flaking damage to *Bos taurus* distal metapodial resulting from bone breaking experimental trials 2 and 7. Fractures across shaft and condyle are similar to those shown in the Schöningen assemblage (1474, 5560+5561, and 8879) and in the stone working experiments. Scale bar = 5 cm.

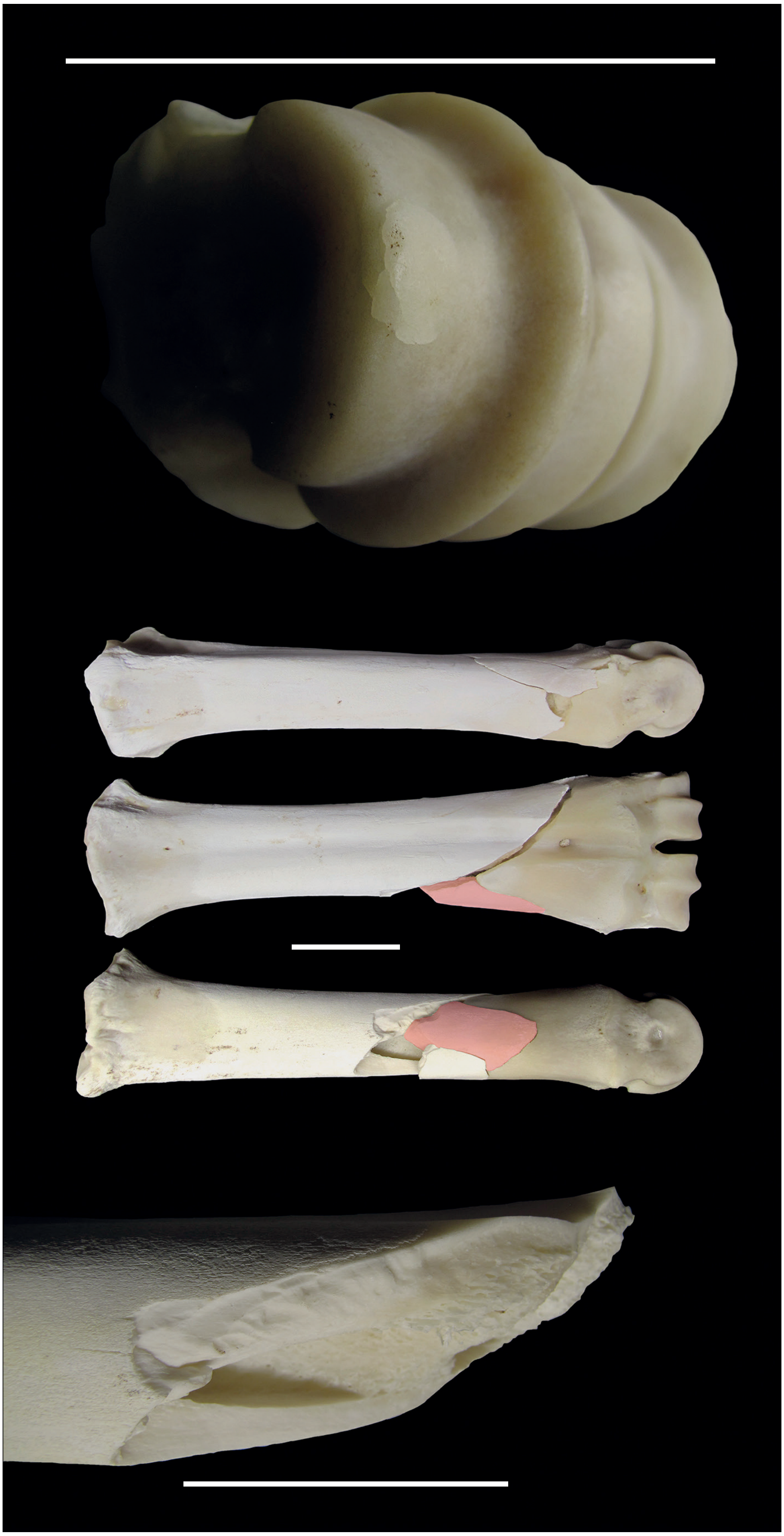

Figure 26 Incipient bone flake on *Bos taurus* distal metapodial from bone breaking experimental trial 4. Hackle marks are visible on the breakage surface. Wedge flake produced by dynamic fracture is shaded in red. Scale bar = 5 cm.

ing damage to the distal condyles produced in trials 2 and 7. No crushing damage was observed on the metatarsal used in trial 4, but a small bone flake not entirely detached from the epiphysis was evident after cleaning of the specimen (**Figure 26**). Both crushing and flaking on the condyles is evident after the extended use of the metapodial in trial 7 (see **Figure 25**); this metatarsal was reused after only five blows (no damage) in trial 2. No damage was observed on the metapodials from trials 3 and 5. In terms of breakage, the same fracture patterns were present in the experimental sample as in the archaeological assemblage, with all metatarsals showing curved breaks across the diaphysis (see **Figures 25 & 26**). The metatarsal from trial 7 also experienced an oblique break across the medial condyle (see **Figure 25**), which is similar to the breaks observed in Schöningen specimens 1474, 5560+5561, and 8879, and one of the fresh metapodials used in the stone working trials (see **Figures 3, 7, 16**).

Discussion

To summarize the results of our experiments, the metapodials were effective in both stone working and bone breaking tasks. Crushing and flaking damage to the distal epiphyses was produced irrespective of the target material, and the observed damage was similar on fresh, dry, and subfossil bone. The difference between flaking and crushing damage appears to be dependent upon the specific trajectory and intensity of the blow against a hard and somewhat stationary target. Duration of use may also play a role in the appearance of different types of damage; crushing damage is more common, but the chance of flaking damage occurring increases with extended use. Based on our experimental trials, there is little to differentiate between the damage produced when striking a metapodial hammer against stone or bone. It is expected that crushing and flaking damage would frequently occur when bone is struck against a material of equal or greater hardness. In this case, the mineral portion of bone, apatite (hydroxyapatite), scores 5 on the Mohs scale of mineral hardness, while flint, and other cryptocrystalline silicates (quartz), measures 7 on the hardness scale. Finally, fracture of the metapodials came about only through multiple heavy blows, beyond that required for retouching dulled cutting edges and most flake-producing tasks. However, we were able to break a subfossil metapodial from a smaller equid species with relative ease; therefore, defatted or dry metapodials may be more susceptible to such breaks, especially under sustained use. In contrast, the bone breaking experiments involved the intentional delivery of a high-impact force with a metapodial to successfully break the target bone for access to the marrow. In such cases, fracture of the metapodial is inevitable with continued use.

Based on these observations, we resolve to define archaeological examples of metapodial soft hammers based solely on the crushing and flaking damage to the proximal and distal ends, damage that is readily distinguished from other taphonomic modifications. Crushing and flaking damage produced in our experimental trials bears noteworthy resemblance to that observed on many of the metapodials in the Schöningen 13II-4 "Spear Horizon" assemblage, attesting to their use as soft hammers. Absent the distinctive crushing and flaking damage, we do not consider the breakage patterns of the metapodials across the shaft to be a good indicator of soft hammer use without further experimentation (see below). On the other hand, we do consider curved breaks across the epiphysis to indicate use as a soft hammer. With that, we have allowed for one exception here: specimen 8879, which includes only a small portion of a distal epiphysis fractured diagonally across the articular surface. This specimen preserves no crushing or flaking damage, but the breakage morphology clearly indicates the bone was struck on the edge of the distal condyle with great force against a hard object. Based on two experimental examples (see **Figures 16 & 25**) and the refitted specimen from Schöningen (5560+5561; see **Figure 7**), this unique type of break is best explained by use as a soft hammer.

Attempting to differentiate the target material (stone or bone) against which the Schöningen

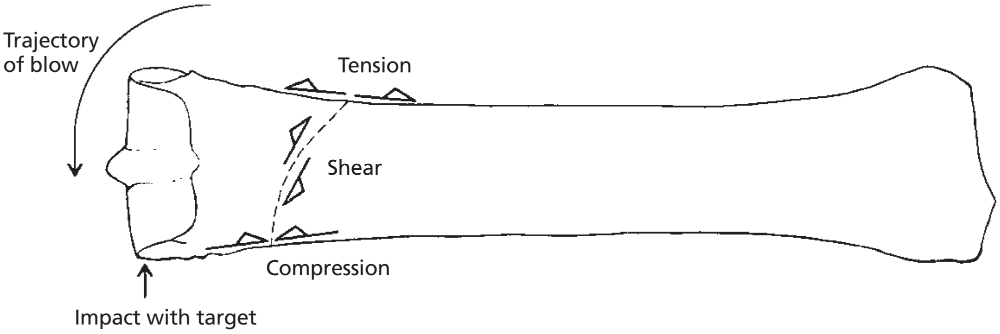

Figure 27 Simplified schematic diagram of forces involved in the use of a bone hammer.

metapodials were struck remains a challenge since the stone working and bone breaking trials yielded nearly identical results. The presence of embedded flint within the bone matrix would provide a clear indication that stone working tasks account for the crushing and flaking damage at some point in the use life of the tool. Flint became embedded in the proximal end of a metapodial during one of the dry bone trials (see **Figure 17**), but this was not replicated in any of the trials with fresh bone. Our analysis of the Schöningen metapodials found no flint inclusions on or near the proximal and distal ends (see also van Kolfschoten et al., 2015b). Ultimately, the presence of embedded flint positively implicates stone working activities, but its absence does not negate the possibility of stone as the target material, nor does it confirm use on bone.

The metatarsals in our experimental trials show remarkably consistent breakage patters, which can provide some insight into the dynamics of their fracture in comparison to other modes of breakage. **Figure 27** depicts the elementary mechanics of the experiments, including trajectory of the blow, impact with the target, and the resulting forces leading to breakage (see Johnson, 1985, and references therein). The shaft on the side delivering the blow to the target bone experiences compression forces upon impact. In turn, the shaft on the side opposite the impact is subjected to tension forces. Shear is introduced as the bone flexes from impact. The spongy nature of the distal epiphysis absorbs the stress waves created by dynamic loading, which, in general, leads to deformation of the epiphysis in the form of crushing and flaking rather than a fracture that cross-cuts the epiphysis. However, off axis loading of trabecular bone can lead to shear failure (Ford and Keaveny, 1996), which accounts for occasional breaks across the distal epiphyses. As cortical bone is stronger in compression than tension, breakage is initiated in the area of greatest tensile strain. The fracture front propagates across the diaphysis in order to relieve the initial strain from impact and eventually merges with other local fracture fronts resulting from bending forces. A wedge flake often detaches from the tension side due to bending failure when the bone flexes, and the fracture surfaces frequently exhibit hackle marks and other stress relief features (see **Figure 26**).

Curved (spiral or helical) breaks across the diaphysis, wedge flakes, and hackle marks all indicate fracture of fresh bone, usually by dynamic loading (Johnson, 1985; but see Haynes, 1983). Bones impacted by a hammerstone can also exhibit these features, but will often include notches with microstriations on the cortical surface, percussion pits, and negative flake scars within the medullary cavity (Blumenschine and Selvaggio, 1988; Capaldo and Blumenschine, 1994; Pickering and Egeland, 2006). Based on our experiments with fresh cattle bones, limbs struck by a metapodial hammer show no surface damage, but do include notches and negative flake scars, in addition to wedge flakes and hackle marks. The presence or absence of these features can be used to identify the manner of breakage for metapodials, albeit with some important caveats, as all bones fractured under dynamic loading will display similar features.

Although it appears that metapodial hammers break in a consistent pattern, there are many processes that can produce the same features on individual bones. The most distinctive characteristic of metapodials broken through use as soft hammers, rather than by impact from a hard or soft hammer, is the lack of impact notches and negative flake scars within the interior wall of the bone. However, metapodials employed as soft hammers could experience multiple cycles of use, including as multi-purpose tools for stone working tasks, and could later be intentionally broken for marrow, both of which could introduce additional impact features not related to use as soft hammers. Furthermore, broken metapodials usually consist of separate proximal and distal ends, with additional fragments of diaphysis. Not all distinguishing fracture features would be present on every bone fragment, thus making it difficult to discriminate between the different modes of breakage without an extensive and successful bone refitting programme. In fact, not all bones broken by hammerstones preserve these fracture characteristics. Capaldo and Blumenschine (1994:731) recorded notches on only 23.3% of bone fragments ≥ 2 cm in controlled breakage experiments. Similar investigations by Pickering and Egeland (2006:466-467) found only 7.9% of bone fragments ≥ 1 cm included notches or were identified as impact flakes; roughly 23% of bones broken (based on complete elements) showed no percussion marks of any kind.

Much of the limb bone assemblage from the Schöningen 13II-4 "Spear Horizon" consists of broken fragments of limb shafts, many of which preserve notches and negative flake scars. There are also numerous examples of impact flakes with striking platforms and bulbs of percussion indicative of impact. However, none include percussion pits or striations that can be confidently attributed to direct impact by a hammerstone or absorption of impact by a stone anvil as opposed to scraping marks, pits, and scores associated with stone working activities (i.e., retouch). Thus, we agree with the assessment of van Kolfschoten et al. (2015b) that breakage of the limb bones at Schöningen was not likely to have been caused by impact from a hammerstone in most cases, but rather from impact by a metapodial hammer. We have demonstrated that it is possible to break open limb bones with blows from a metapodial hammer, and the surface modifications, or lack thereof, on the broken limb bone assemblage provide additional support for this conclusion. Intentionally fractured limb bones are ubiquitous at Palaeolithic sites, but the lack of hammerstones is somewhat peculiar, and the presence of metapodial hammers is unique to the Schöningen archaeological deposits. In this context, bone marrow appears to have been an important component of the hominin diet at Schöningen, well worth the additional costs of recovery that required the procurement of metapodials to break open the bones.

Owing to the dozens of bones in the Schöningen 13II-4 "Spear Horizon" assemblage that preserve pits and scores from stone-working activities, including on several of the metapodials mentioned here, we suspect some of the crushing and flaking damage to the metapodials can also be attributed to heavy-duty stone working tasks. We have demonstrated that the proximal and distal ends of the metapodials are well suited to flake producing tasks.

With these dual stone working and bone breaking capabilities, it appears that the metapodial hammers completely supplanted hammerstones in the Schöningen hominin toolkit. Any task usually attributed to a hammerstone could have been taken up by a metapodial hammer. While there does not appear to have been selection for specific bones used as retouchers (van Kolfschoten et al., 2015b), other than a broad preference for limb bone shafts, metapodials were deliberately selected over all other bones for use as heavy-duty hammering tools.

Another Schöningen locality, site 12II-4, which is located roughly 1 km to the north and thought to be contemporaneous with the "Spear Horizon", also includes a variety of bone tools and few lithic artefacts relative to faunal remains (Julien et al., 2015). This commonality indicates a shared bone tool technology and behavioural link across multiple sites along the Schöningen lakeshore and vicinity. Because metapodials were useful for multiple tasks, it is possible that some of these tools even moved around the landscape, as did the Schöningen spears and other lithic tools. Based on the rarity of spruce *(Picea)* in the pollen assemblage (e.g., Urban, 2007), the spears were brought to the site as fully functioning hunting weapons, with some possible processing or reworking at the "Spear Horizon" site (Schoch, 2015). As for the stone tools, Serangeli and Conard (2015) suggest a relatively high proportion of the lithic artefacts were imported to the site in finished form and re-sharpened on site. With such an abundance of prey carcasses at the site, it would be likely that more metapodials were taken away from the "Spear Horizon" site than were imported. The movement of bones across the landscape could account for the remains of rare species used as tools at various Schöningen localities, including the *Homotherium* humerus from the "Spear Horizon" (see Serangeli et al., 2015; van Kolfschoten et al., 2015b) and the lone specimen from a large cervid (cf. *Megaloceros giganteus)* from Schöningen 12II-2 (Julien et al., 2015).

This presumption may be difficult to reconcile with the fact that nine wooden spears and a lance were abandoned at the site, but there does appear to be a distinct underrepresentation of metapodials in the overall faunal assemblage. Skeletal part abundances reported by van Kolfschoten et al. (2015a:144) show a deficit of metapodials relative to other limb bones. Humerus and radius are represented by 167 and 166 specimens, respectively, whereas only 60 metacarpal specimens were identified. The same pattern holds for the hind limb, with 227 specimens for both femur and tibia, and only 72 metatarsal specimens. An additional 31 unidentified metapodial fragments are listed in the inventory. These abundances are described as "number of elements"; however, the figures are almost certainly based on number of identified specimens and not a representation of complete skeletal elements. Based on our preliminary observations, the abundance of metapodials is much lower than other limb bones when using other derived measures, such as minimum number of elements. Regardless of how the bones are counted, the lesser abundance of metapodials cannot be easily explained as a matter of preservation or other taphonomic processes, such as carnivore gnawing. Overall, the bone assemblage is extraordinarily well preserved and all portions of the skeleton are preserved in various frequencies. Bone density studies show that individual portions of metapodials (i.e., proximal, distal, and mid-shafts) are as dense or denser than comparable portions of nearly all other limb bones (Lam et al., 1999:351-353). Carnivore damage to the assemblage, and specifically to metapodials, is rare. Thus, removal of metapodials from the site by hominins is a legitimate explanation for their relative absence. It is possible that metapodials left the site as "riders" with more valuable portions of the carcasses, such as the skins, which would also account for the low number of phalanges. As a sizeable proportion of the metapodial fragments present at the site were used as tools, these bones were valued in their own right as raw material, despite their almost negligible food value (Outram and Rowley-Conwy, 1998).

There is no mistaking the parallels here with the club-wielding *Australopithecus prometheus* and the osteodontokeratic culture professed by Dart (1957), but this is a far cry from the bloodthirsty apes of Dart's conjuring. These were intelligent hominins, skilled hunters, and expert craftsmen who utilized a wide range of non-lithic raw materials for weapons and tools. Faced with an apparent lack of suitable raw material for hammerstones, the Schöningen hominins relied on technological ingenuity to replace these critical components of the lithic *chaîne opératoire* and butchery process with objects readily available on the landscape. Fresh animal carcasses or previous kills could have served as a sort of bone quarry for immediate or later use (e.g., Hannus, 1989; Johnson, 1985, 1989; Steele and Carlson, 1989; Holen, 2006). While this behaviour may be rooted in the Early Stone Age (e.g., Backwell and d'Errico, 2004) well beyond the time of the "Spear Horizon", the Schöningen hominins display a unique relationship with horse bones as a raw material for tools on an unprecedented scale. This may seem a trivial side note in hominin prehistory, but recognising the utility of bone, and not just a sterile byproduct of a meal, constitutes a major leap forward in hominin behavioural evolution.

As the Schöningen metapodials were likely used to break bones for marrow and in lithic manufacture, it has been suggested that these implements may constitute "the first clear evidence of multi-purpose bone tools in the archaeological record" (van Kolfschoten et al., 2015b:261). We agree with the notion that these were multi-purpose tools, but caution that the Schöningen metapodial hammers can be considered multi-purpose tools only insofar as hammerstones qualify as multi-purpose tools. We prefer to interpret the use of these metapodial hammers from the perspective of their Palaeolithic handlers – as replacements for hammerstones.

The more important concern is the circumstances under which this replacement took place. Substituting bone for stone could have developed out of a necessity to find an alternative raw material for heavy-duty stone working tasks and breaking bones when suitable hammerstones were not accessible. Upon the recognition of bone as a useable resource, metapodials became a convenient substitute for hammerstones, as they would have been readily available from fresh animal carcasses or at known surface accumulations of animal bones. Perhaps stemming from this necessity and convenience, metapodial hammers came to be preferred over hammerstones for these various tasks. The circumstances that drove this innovative behaviour must have been prevalent across the greater Schöningen landscape, where hammerstones are all but absent at multiple Middle Pleistocene localities (Serangeli and Conard, 2015), yet the bone tool industry is well developed in the "Spear Horizon" and within contemporaneous archaeological layers at site complex 12II (Julien et al., 2015).

As the Schöningen 13II-4 "Spear Horizon" represents multiple hunting episodes along the shoreline of the ancient lakeshore, there is some time depth to the archaeological deposit. Therefore, the abundance of metapodial tools at the site suggests a distinct diachronic tradition transmitted through time. This technological innovation did not spread to neighboring regions and was not developed independently in other areas, but rather the use of these metapodial tools represents a truly unique feature of the Schöningen cultural landscape.

Conclusion

Building on the previous work of Voormolen (2008) and van Kolfschoten et al. (2015b) we described 46 bones with damage from use as soft hammers from the archaeological deposits at the Schöningen 13II-4 "Spear Horizon". Horse metacarpals and metatarsals were deliberately selected for use in heavy-duty hammering tasks by Middle Pleistocene hominins as evidenced by the crushing and flaking damage to the proximal and distal ends. Several horse humeri show similar damage to the distal condyles, and metapodials from bovids and cervids were also used, albeit to a limited extent. We have demonstrated the utility of these soft hammers in both stone working and bone breaking tasks. Various aspects of the faunal and lithic assemblages recovered from the "Spear Horizon" are consistent with a multi-purpose utility of these bone implements. Breakage features suggest most of these bones were used while fresh, while others may have been defatted or dry and selected from the existing bone refuse at the site. The lesser abundance of metacarpals and metatarsals relative to other limb bones in the overall assemblage suggests that some metapodials were transported away from the site for use at other localities across the Schöningen landscape. In a similar fashion, bones may have been brought to the "Spear Horizon" site from other locations. Considering the scarcity of large hammerstones at any of the Schöningen Middle Pleistocene sites, we conclude this large assemblage of metapodial hammers reflects the replacement of hammerstones with bone hammers for various stone working and breaking bones tasks.

The Schöningen 13II-4 "Spear Horizon" will be forever remembered for the hunting weapons from which the site draws its name. While these spears are truly extraordinary, there are other known Palaeolithic examples from Clacton-on-Sea, UK (Warren, 1911), and Lehringen, Germany (Movius, 1950). The metapodial hammers, on the other hand, are exclusive to Schöningen, and not just in the "Spear Horizon", but also at Schöningen 12II. At present, no comparable tools have been reported from other Palaeolithic sites in Europe, or elsewhere. This innovative replacement of hammerstones with bone hammers was driven out of necessity and demonstrates the capability of Middle Pleistocene hominins to make cultural adjustments in technology based on a particular set of available resources. The creativity displayed in the development and use of these bone tools is a hallmark of the human species, much more so than the artefacts themselves. Evidence from Schöningen reveals that this creative tendency is deeply ingrained in the behaviour of our recent hominin ancestors.

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