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Humans, bones and fire: Zooarchaeological, taphonomic, and spatial analyses of a Gravettian mammoth bone accumulation at Grub-Kranawetberg (Austria)

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ABSTRACT

The role of humans in the formation of Gravettian mammoth bone accumulations of central and eastern Europe is a heavily debated topic. Grub-Kranawetberg, a multi-layered Gravettian open-air site in eastern Austria, yielded a bone accumulation in the vicinity of a campsite. Zooarchaeological, taphonomic, and spatial analyses of this assemblage offer evidence on both human subsistence and formation of mammoth bone accumulations. The deposit is dominated by *Mammuthus primigenius* but also includes *Coelodonta antiquitatis*, *Rangifer tarandus*, *Equus* sp., *Megaloceros giganteus*, *Canis lupus*, *Ursus* cf. *arctos* and *Lepus* cf. *timidus*. The presence of butchery marks on remains of both megafaunal taxa indicates a human accumulated assemblage. The absence of carnivore gnaw marks suggests that humans had primary access to meaty skeletal parts. An indication that humans occupying the adjacent campsite interacted with the bones is seen in the rearticulation of a left upper first molar of a mammoth from the campsite with its matching right first upper molar found in the bone accumulation. The deposit is further characterized by various indications of fire evident in lenses of burned sediment and abundant traces of heating faunal remains. The varied colours of burned bone, as well as reddish burned loess show that the accumulation was subjected to a wide range of fire temperatures. The current results argue for the intentional use of fire as waste removal strategy.

1. Introduction

The role of humans in the formation of Upper Palaeolithic mammoth bone accumulations is a heavily debated topic, especially in regions such as central and eastern Europe where such accumulations are common (e.g. Haynes, 1991; Soffer et al., 2001; Soffer, 2003; Svoboda et al., 2005). There is a fair amount of variation both in structure and composition of Upper Palaeolithic mammoth bone accumulations (e.g. Soffer et al., 2001; Soffer, 2003; Gaudzinski et al., 2005; for the middle Danube region see Bosch, 2009; Brugère et al., 2009). Reasons for accumulation may likewise be varied, and several hypotheses on these causes have been put forward (for a summary see Soffer, 2003).

Despite the lively debate on the role of humans in the formation of mammoth bone accumulations, few studies have focused on the role of fire in these accumulations. A number of sites show traces of burning on the faunal remains, such as Předmostí I-06 (Beresford-Jones et al., 2010) and Dolní Věstonice II (Svoboda, 1991; Beresford-Jones et al., 2010). Evidence of fire, in particular determining the process that caused the fire, could be useful for distinguishing between natural and human-influenced mammoth bone accumulations. Therefore, the study of the role of fire in the formation of the mammoth bone accumulations is of great interest.

Studies on burned bones in hearths are more frequent. For example, studies on bone used as fuel have been undertaken (e.g. Théry-Parisot, 2002; Villa et al., 2002, 2004; Costamagno et al., 2005; Théry-Parisot et al., 2005) and a methodology for distinguishing whether or not burned bone was used for fuel has been recently established (Théry-Parisot et al., 2005). Other reasons for burning bones that have been discussed up to now include bone grease extraction (e.g. Binford, 1978; see also Costamagno, 2010),

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roasting (e.g. Buikstra and Swegle, 1989; David, 1990), and waste removal (e.g. David, 1990; Soffer et al., 1997; Villa et al., 2004).

Previous studies on burning have mainly focused on medium and large sized animals. Evidence of burning on megafaunal remains such as those of mammoths are sometimes mentioned (e.g. Soffer, 1985; Soffer et al., 1997; Haynes, 2002, Table 5.8), but to the authors' knowledge, rarely studied in depth (but see Beresford-Jones et al., 2010; Fladerer et al., 2010; S. Péan, pers. comm.).

Therefore, the focus of this paper is to explore the role of fire and humans in mammoth bone accumulations. Studies show that (1) mammoth remains dominate the faunal spectra in central and eastern Europe during the Upper Palaeolithic (e.g. Musil, 1968; Fladerer, 2001), and that (2) they were accumulated in various ways (Haynes, 1991; Soffer et al., 2001; Soffer, 2003; Bosch, 2009; Brugère and Fontana, 2009). Regarding human accumulated mammoth bone piles, several interpretations for the utility of these accumulations have been put forward, including the collecting of mammoth remains by humans for subsistence (Fladerer, 2001; Svoboda et al., 2005; Fladerer and Salcher, 2008; Péan et al., 2010), bones and ivory as raw material for making tools and personal adornments (e.g. Antl and Fladerer, 2004; Antl, 2005; Brugère and Fontana, 2009), or as building material for structures such as the Epigravettian so-called mammoth bone dwellings on the eastern European plain (e.g. Soffer, 1985, 2003; Pidoplichko, 1998). To better understand the processes involved in the collection of mammoth remains at these sites, it is important to not only look at the bone accumulations as such but also to study them in the broader context of the site complexes in which they were recovered (Brugère and Fontana, 2009; Djindjian and Iakovleva, 2010; Péan et al., 2010).

This paper presents the results of the analysis of a mammoth bone accumulation at Grub-Kranawetberg, a multi-layered Gravettian open-air site in Austria. The site yielded a bone accumulation adjacent to a campsite (e.g. Antl and Fladerer, 2004; Antl-Weiser, 2008). The bone pile is characterized by various indications of burning evident in lenses of burned sediment and abundant traces of heating on the bones. Zooarchaeological, taphonomic, and spatial analyses of this assemblage offer evidence that allows the following questions to be addressed: How do mammoth bone accumulations form? What role does fire play in the formation of bone accumulations?

2. Grub-Kranawetberg

Grub-Kranawetberg (48° 25′ 14″N, 16° 49′ 46″E) is located approximately 40 km northeast of Vienna in Lower Austria (Fig. 1). On a broader scale, the site is placed in the middle Danube region, which comprises Lower Austria, Moravia, western Slovakia, and the Hungarian plain. Many archaeological sites are located in this loess-rich region, among them some of the more famous Gravettian localities of Willendorf II, Pavlov, and Dolní Věstonice. The site of Grub-Kranawetberg is situated 196 m above sea level on the southern slope of a hill framed in the north and south by small creeks leading into the nearby March River valley. While the site is known from surface collections since the 1970s, new surface finds in 1993 made a first rescue excavation necessary. Since then, fieldwork directed by Walpurga Antl-Weiser (Natural History Museum Vienna) has exposed a total of ca. 265 m^2 in seven trenches (Fig. 2). Up to now, approximately 70,000 objects have been piece plotted. During the first three years of investigation (1993–1995) a bone accumulation was excavated, consisting of one archaeological horizon (hereafter AH) (Antl-Weiser et al., 1997; Antl and Fladerer, 2004; Antl-Weiser, 2008). The bone accumulation was excavated in three trenches (Fig. 2). In the southernmost part of the excavation area the archaeological horizon was destroyed by agricultural ploughing (Fig. 3). The bone pile is dated to 25.220 ± 250 BP (GrA-9062; charcoal). Besides the bones, only 30 lithics, 20 stones, two pieces of red ochre, 14 molluscs and mollusc fragments including one perforated mollusc were recovered. These finds do not show traces of burning. Additionally, 14 charcoals were piece plotted. As evident structures, some lenses of burned loess, charcoal and ash were documented (Fig. 4) (Antl-Weiser et al., 1997; Antl and Fladerer, 2004; Antl-Weiser, 2008).

Starting in 1995, the excavation was extended to an area 20 m east of the bone accumulation (Fig. 2). In this area, which has been under continuous excavation, four archaeological horizons (AH 1–4) have been recognized. The lowermost AH 4, dated to ca. 25 ka BP (Antl-Weiser, 2008), comprises several features such as small

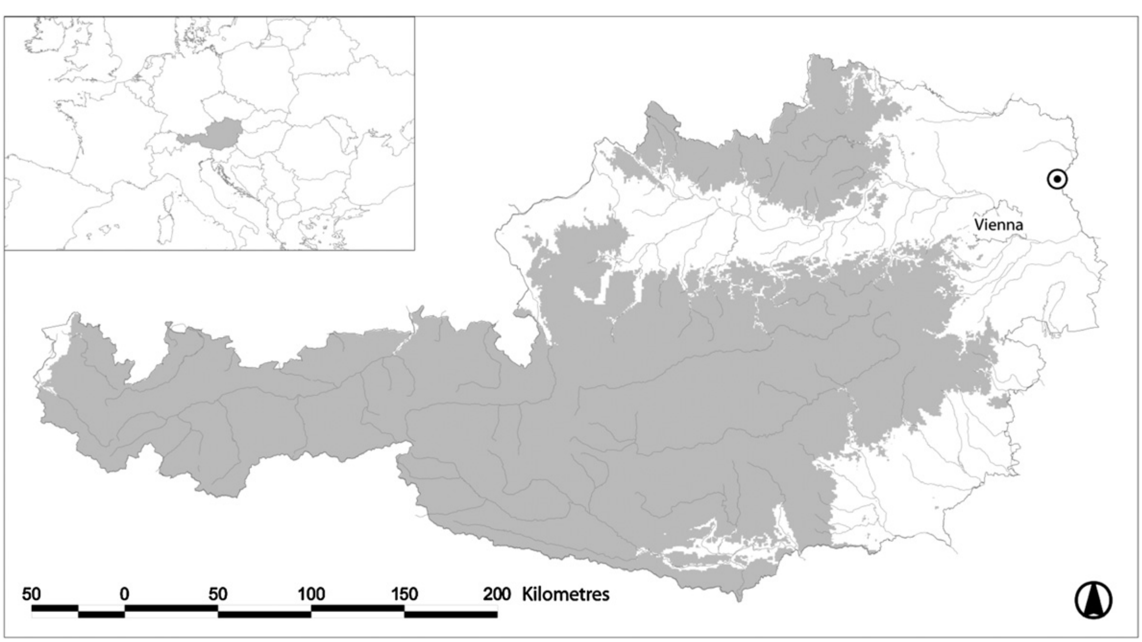

Fig. 1. Location of Grub-Kranawetberg (Austria). Grey areas: Elevation >500 m asl. Inset: Map of Europe showing Austria (grey).

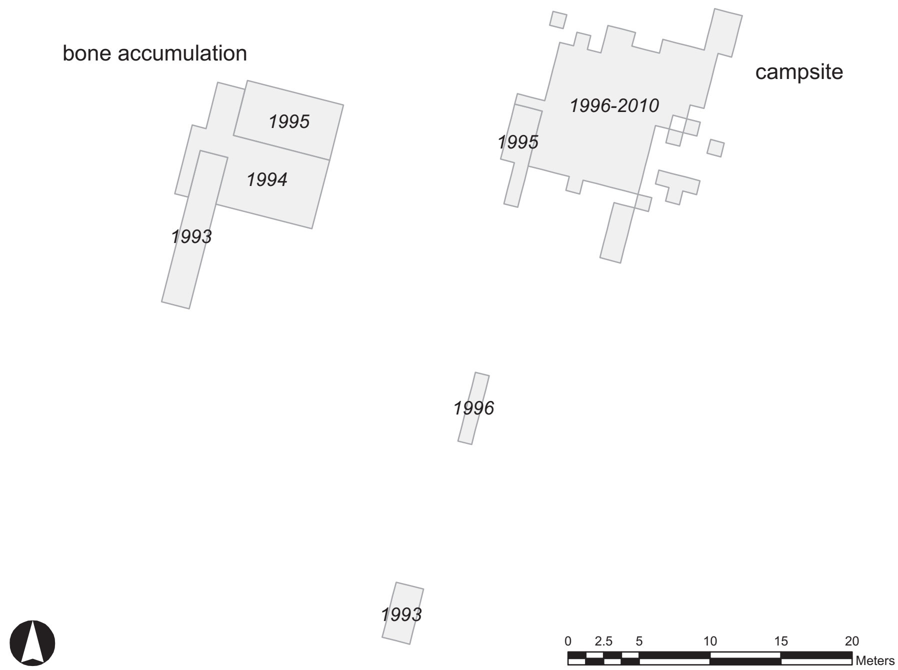

Fig. 2. Grub-Kranawetberg: Overview of the location of the trenches excavated between 1993 and 2010. The bone accumulation is located in the northwest and comprises three excavation trenches. The campsite area is located in the northeast and comprises two excavation trenches. Excavations years are plotted on the trenches.

pits and two hearths. The numerous finds include worked bone (e.g. needles, awls, and spatulas), adornments (e.g. ivory beads and perforated shells), and two human teeth (Antl-Weiser, 1995, 1996, 1999, 2008; Antl-Weiser et al., 1997; Antl-Weiser and Teschler-Nicola, 2000; Nigst, 2003, 2004a,b, 2006; Antl and Fladerer, 2004; Teschler-Nicola et al., 2004; Antl, 2005). Interestingly, it appears that the AH 4 is contemporaneous with the bone accumulation (Bosch, 2009). Evidence for this association involves an upper left first molar of mammoth found in the AH 4 which belongs to the same maxilla as a right upper first molar found at the bone accumulation. In the bone accumulation, *Mammuthus primigenius* dominates the faunal assemblage (Table 1). Complete specimens as well as numerous fragmented faunal remains characterize the bone pile (Table 2). The absence of carnivore gnaw marks supports the assumption that the remains were not strongly affected by scavenging carnivores and in turn, that humans would have had first access to these meaty parts. Based on mammoth skeletal element representation and the rarity of stone artefacts, the bone accumulation was interpreted as a dump zone where carcass parts were transported and deposited after butchering (Antl and Fladerer, 2004; Antl-Weiser, 2008).

3. Methods

3.1. Field methods

During excavation, standard methods of Palaeolithic excavations in loess sediments were employed. These methods include: three-dimensional recording of all objects found *in situ*, fine mesh (2 mm) dry screening of all sediment, and labelling of the finds with a unique identification number consisting of the year of excavation and a running number. Occasionally, faunal remains were found as parts of long bones that were fragmented but still in place; when possible, these were stabilized in the field and collected *en bloc* to be further excavated and prepared in the laboratory of the Institute of Palaeontology (University of Vienna).

3.2. Laboratory methods

For analysis of the spatial patterns, the hand drawn field maps were scanned, georeferenced, and redrawn within a geographic information system (GIS). The faunal database is linked to the spatial location data of the faunal remains and used for plotting. Wherever possible, specimens were assigned to species and skeletal element. For NISPs (number of identified specimens) all specimens that could be assigned to both species and element were taken into account. MNI (minimum number of individuals) calculations take into consideration side, age and size of the bone (e.g. Lyman, 2008). Analyses include anthropogenic marks (e.g. cut and hammerstone impact marks) and animal modifications (e.g. gnaw marks, punctures) as well as other attributes such as weathering, burning, decalcification, and root etching. When studying burning it is important to look at the small fraction of unidentified bones in addition to the identified specimens, as burned bone is highly prone to fragmentation (Stiner et al., 1995; Villa et al., 2004). Therefore, an aggregate analysis was done on the portion of the faunal assemblage that is <4 cm. In order to quantify burning damage as well as to infer if bones were directly or indirectly exposed to fire, these remains were counted and sorted by burning stage (after Stiner et al., 1995) (Table 3). Additionally, the possibility of bone use as a means of fuel was addressed. Experiments show that spongy bone can be useful as fuel, whereas compact bone is not (Costamagno et al., 2005; see also Villa et al., 2004). The small bone fraction (<4 cm) was divided into spongy and compact bone according to the dominant (>50%) bone structure (after Villa et al., 2004) (Table 3). Mammoth molars display a wide variety of colours, ranging from white, beige to black which makes it difficult to assign burning stages that are based on colour. Additionally, to the authors' knowledge, no detailed study on the effects of burning temperature on the structure and colour of ivory has been done. Due to difficulties of assigning dental remains to the seven burning stages defined by Stiner et al. (1995), all remains were analyzed for burning in terms of presence/absence. To infer the role of fire in the bone accumulation's formation, the results of the

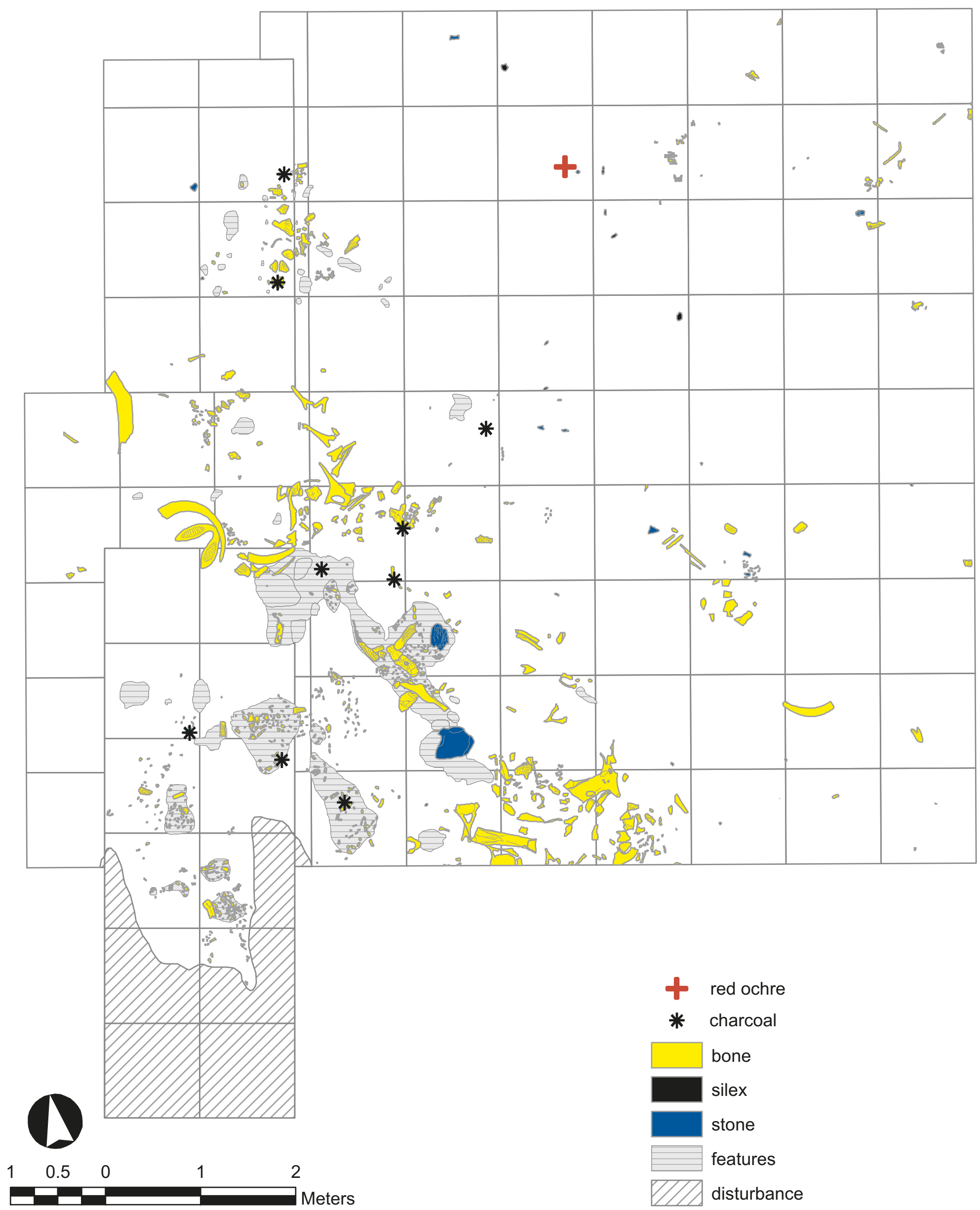

Fig. 3. Grub-Kranawetberg bone accumulation: Spatial distribution of all find categories. Bones include burned and unburned specimens.

analyses were tested against the expectations of eight models derived from the literature.

4. Results

The bone accumulation is characterized by various indications of burning evident in lenses of burned sediment and abundant traces of heating on the bones. The varied stages of burned bone, as well as reddish burned loess show that it was subjected to a wide range of fire temperatures. The following paragraphs present the results of analyses of the features, faunal and other remains at the bone accumulation.

4.1. Features

The evident structures in the bone accumulation are lenses of burned sediment, charcoal and ash. These lenses vary in size and most are of rather amorphous shape. Size ranges from small patches with a diameter of 0.10 m to larger ones with a maximum length of up to 2.0 m. Most of these features are located in the southeastern part of the excavation area (Fig. 4). The lens of burned reddish to dark brownish sediment was approximately 3–4 cm thick. The other lenses of burned sediment and charcoal and ash were between 1 and 3 cm thick. Only smaller lenses of ashy sediment are located north of the lenses of burned sediment. These features, especially the lenses of burned loess, document *in situ* fire. The abundant charcoal in the burned sediment indicates that wood was used as fuel. Ashes are mixed with charcoal and burned sediment, suggesting a rather quick burial of the site, as dry ash is very easily blown away or washed out (e.g. Mallol et al., 2007). The spatial distribution of the lenses of burned loess, charcoal, and ashy sediment does not show any specific patterning. Generally, the faunal remains overlap spatially with these features. The eastern and northeastern parts of the bone accumulation with a low density of faunal remains do not contain any patches of burned sediment or ash lenses.

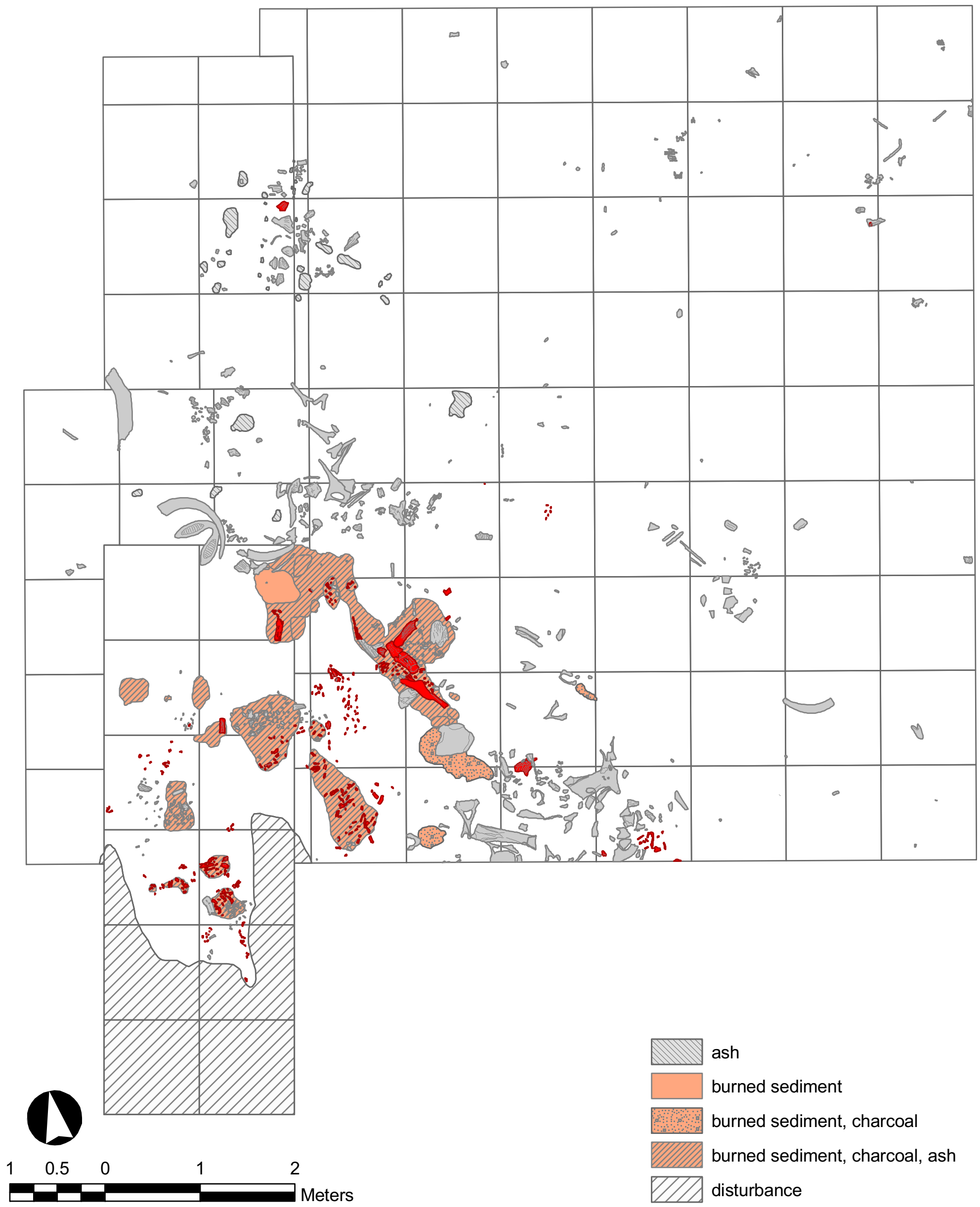

Fig. 4. Grub-Kranawetberg bone accumulation: Spatial distribution of burned faunal remains (red), not burned find categories (grey) and features.

4.2. Faunal remains

M. primigenius remains dominate the faunal assemblage, but also *Coelodonta antiquitatis*, *Equus* sp., *Rangifer tarandus*, *Megaloceros giganteus*, *Canis lupus*, *Ursus* cf. *arctos* and *Lepus* cf. *timidus* are present (Table 1, spatial distribution: Fig. 5). Mammoth is mainly represented by dental and axial elements. An MNI of 8 mammoths could be derived from molars (Bosch, 2009, 2010). All other taxa are represented by only a few remains (Table 1). The bone pile is characterized by large, complete elements (e.g. innominate and crania) of megafaunal species. Also common are clusters of elements belonging to one individual. For example, a cluster of *M. primigenius* skull, molar and ivory fragments was found. Overall, however, the faunal remains are highly fragmentary, with the vast majority (97%) smaller than 4 cm. This may largely be due to the high incidence of burning, as the burning of complete bones results in high fragmentation rates (Costamagno et al., 2005) and burned bones are prone to fragmentation (Stiner et al., 1995). Due to the fragile state of the burned bones at the time of excavation, further fragmentation commonly occurred.

The possibility of density-mediated preservation of the faunal remains has to be discussed. No density values have been described for mammoths specifically or any other megafaunal species. However, although molars, the densest elements, make up for 21.54% of the total faunal assemblage, spongy bone, that is most vulnerable to post-depositional bone attrition, makes up 20.82%. Further, corpora of several mammoth vertebrae are completely preserved. The preservation of these elements that are most vulnerable to bone destroying processes indicates that all remains were equally preserved, without bone density playing a large role.

Human modifications are not extensive but evident from butchery marks on innominate remains of both mammoth and woolly rhinoceros, which include impact fractures ($n = 5$) accompanied by several green-breaks. Additionally, meaty parts, such as long bones and ribs, are frequent. No cutmarks could be identified, but it has been suggested that in megafaunal remains the thick skin

Table 1
Grub-Kranawetberg bone accumulation: Skeletal element representation per taxon, expressed as NISP, MNE, MNI and %NISP. In the %NISP column bold numbers represent %NISP of the total faunal assemblage, normal numbers give %NISP within each species. In the %burned column bold numbers represent %burned within the species, normal numbers give %burned within each element.

element per species	NISP	MNE	MNI	%NISP	n burned	% burned
Mammuthus primigenius	**407**	**50**	**8**	**93.56**	**92**	**22.60**
cranium	8	3	3	2.68	0	0
mandible	1	1	1	0.33	0	0
molar	134	14	8	44.82	23	17.16
ivory	66	5	3	22.07	25	37.88
cervical vert.	6	6	2	2.01	0	0
thoracic vert.	9	7	1	3.01	0	0
lumbar vert.	3	3	1	1.00	0	0
sacrum	2	1	1	0.67	0	0
rib	57	7	1	19.06	44	77.19
innominate	9	2	2	3.01	0	0
tibia	4	1	1	1.34	0	0
***Equus* sp.**	**10**	**7**	**2**	**2.30**	**0**	**0**
cranium	1	1	1	10.00	0	0
dental element	7	4	1	70.00	0	0
tibia	2	2	2	20.00	0	0
Coelodonta antiquitatis	**8**	**6**	**1**	**1.84**	**0**	**0**
cranium	1	1	1	12.50	0	0
tooth	1	1	1	12.50	0	0
thoracic vert.	1	1	1	12.50	0	0
lumbar vert.	2	1	1	25.00	0	0
sacrum	1	1	1	12.50	0	0
innominate	2	1	1	25.00	0	0
Megaloceros giganteus	**5**	**5**	**1**	**1.15**	**0**	**0**
teeth	5	5	1	100.00	0	0
Rangifer tarandus	**1**	**1**	**1**	**0.23**	**0**	**0**
antler	1	1	1	100.00	0	0
Canis lupus	**2**	**2**	**1**	**0.46**	**0**	**0**
tooth	1	1	1	50.00	0	0
radius	1	1	1	50.00	0	0
Ursus* cf. *arctos	**1**	**1**	**1**	**0.23**	**0**	**0**
phalange	1	1	1	100.00	0	0
Lepus* cf. *timidus	**1**	**1**	**1**	**0.23**	**0**	**0**
radius	1	1	1	100.00	0	0

and large body-size might prevent the production of traceable cutmarks on the remains (Haynes, 1991). Also, the highly fragmentary state of the remains could have obscured potential cutmarks. Ribs and rib fragments found around the fireplaces in AH4 of the campsite area display a high incidence of cutmarks (Antl et al., in preparation).

The absence of carnivore gnaw marks suggests that humans had primary access to meaty skeletal parts. An indication that humans occupying the adjacent campsite interacted with the bones is documented by the rearticulation of a left upper first molar of a mammoth from the campsite with its matching right first upper molar found in the bone accumulation (Bosch, 2009).

Post-depositional taphonomic processes include root etching and calcareous concretions. Decalcification is common especially on dental remains. Bone weathering is superficial (stage 0–1 after Behrensmeyer, 1978). Carnivore and rodent gnaw marks could not be detected. Evidence on bone weathering and absence of gnaw marks suggests that the faunal remains were not long exposed and buried quickly. There is no spatial separation (in *x*, *y*, and *z*) between the faunal remains of the individual species, nor is there evidence for differences in spatial distribution between burned and unburned remains. Evidence that the accumulation did not suffer from major post-depositional processes is also provided by larger bone fragments that were broken but found in their original shape.

Table 2
Grub-Kranawetberg bone accumulation: Number and percentages of burned (stages 1–6 after Stiner et al. (1995)) and unburned (stage 0 after Stiner et al. (1995)) elements per size category (larger and smaller 4 cm) and within size category broken down by spongy bone, compact bone, ivory and molar.

elements	unburned	% unburned	burned	% burned	total *n*
n (<4 cm)	**10962**	**54.99**	**8972**	**45.01**	**19934**
spongy bone	1950	47.38	2166	52.62	4116
compact bone	3011	44.57	3745	55.43	6756
ivory	2188	45.84	2585	54.16	4773
molar	3813	88.90	476	11.10	4289
n (>4 cm)	**633**	**89.66**	**73**	**10.34**	**706**
spongy bone	171	93.96	11	6.04	182
compact bone	229	78.69	62	21.31	291
ivory	77	100.00	0	0.00	77
molar	156	100.00	0	0.00	156
total	**11595**	**56.18**	**9045**	**43.82**	**20640**

Table 3
Grub-Kranawetberg bone accumulation: Number and percentages of spongy and compact bone (fraction < 4 cm) per burn stage. Burn stages after Stiner et al. (1995).

bones *n*	spongy	% spongy	compact	% compact	total *n*
stage 0 (unburned)	1950	39.31	3011	60.69	4961
stage 1 (<50% carbonized)	448	26.15	1265	73.85	1713
stage 2 (>50% carbonized)	807	39.44	1239	60.56	2046
stage 3 (fully carbonized)	444	54.55	370	45.45	814
stage 4 (<50% calcined)	119	35.63	215	64.37	334
stage 5 (>50% calcined)	107	41.00	154	59.00	261
stage 6 (fully calcined)	241	32.44	502	67.56	743
total	4116	37.86	6756	62.14	10872

4.3. Burning

As previously mentioned, a substantial portion (44%) of all faunal remains is burned. Interestingly, when looking at the identifiable bones, only mammoth remains show traces of fire exposure (Table 1). However, other taxa could be represented in the form of burned unidentifiable fragments. Specific elements, such as molars, ivory as well as rib fragments have been affected by fire. This pattern may be partly due to the higher probability of identification of small fragments of these particular elements. These are also most abundant among the identifiable skeletal elements of *M. primigenius* (Table 1). Long bone fragments of megafauna were also occasionally burned, but in all cases fragmentation prevented identification to element.

The importance of studying the small-sized and unidentifiable bone fragments of an assemblage affected by fire is again established by the difference in percentage of burning in both categories (Table 2). A total of 99% of the burned bones in the Grub-Kranawetberg bone accumulation is smaller than 4 cm. When looking at bone fragments <4 cm only, an aggregate analysis shows that almost half (45%) of them are burned. Carbonized fragments (burn stage 1–3) are most frequent among the burned bone (77%), while the remaining 23% show traces of calcination (burn stages 4–6 after Stiner et al., 1995). The spongy bone/compact bone ratio is similar in both the burned and unburned small bone (<4 cm) fraction (Table 3).

Direct exposure to fire of faunal remains can be argued for based on the presence of calcined bones (Stiner et al., 1995, 231), and thus that the bones were lying on the surface at time of the fire. Calcined bones further indicate that the fire burned longer than the usual natural fire (David, 1990). In situ burning can be argued for by the overlapping spatial distribution of burned bones and burned loess (Fig. 4). Further, evidence for human involvement is provided by distribution of burning damage on the bones. Field records indicate that in some cases the lower surface of bones was burned, whereas the upper surface does not show traces of fire. This suggests that bones were put on a burning fire by humans.

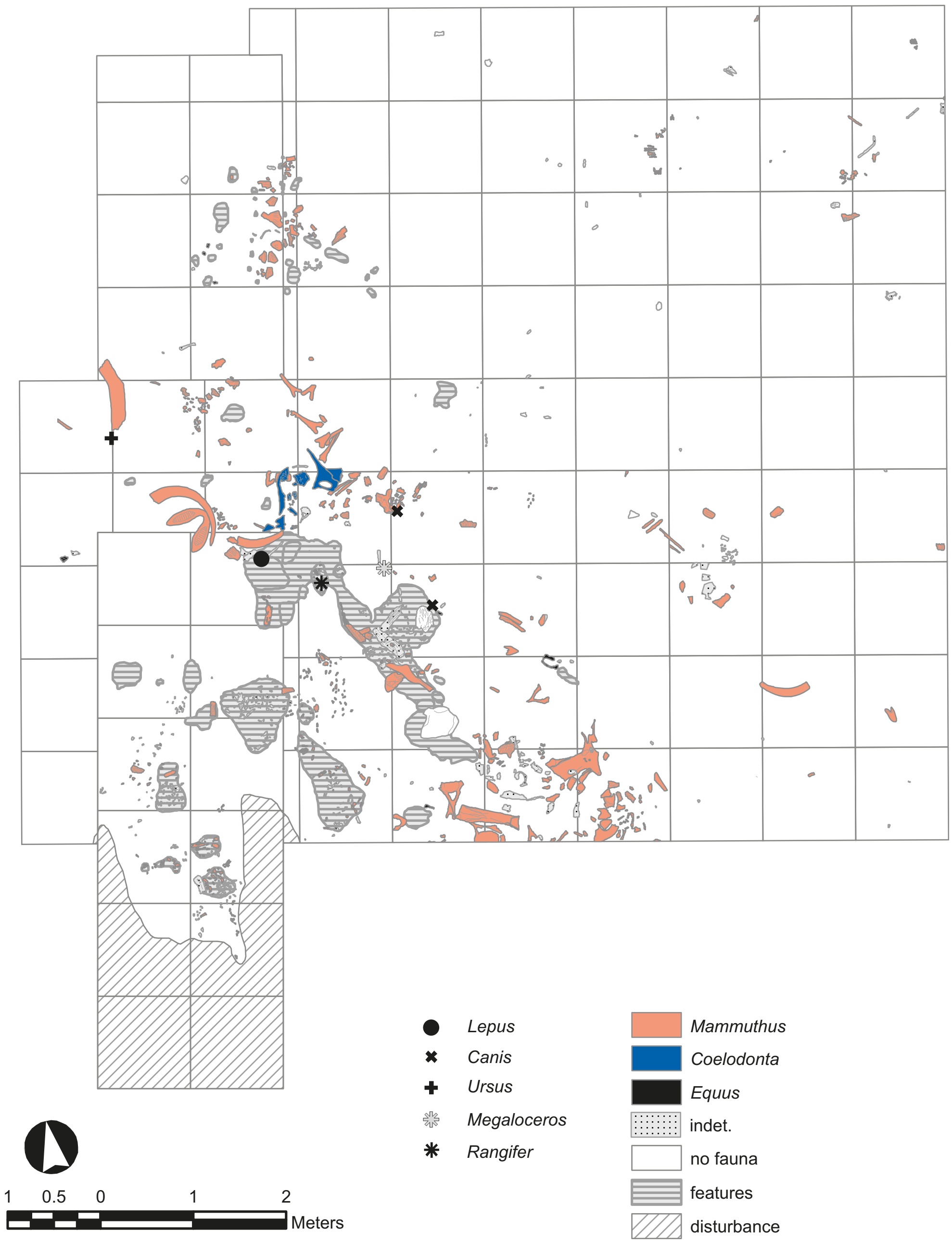

Fig. 5. Grub-Kranawetberg bone accumulation: Spatial distribution of faunal elements per species. Bones include burned and unburned specimens. All 5 *Megaloceros* specimens are located at the same position, therefore only one symbol is used.

5. Model testing: how did the bone accumulation form?

In order to assess how the bone accumulation formed and which site formation processes were involved, models to be tested against the archaeological record were formulated. The models and their expectations are mainly based on published information and they focus on the role of fire in the formation of the bone accumulation. The following paragraphs present each model and evaluate it with the data coming from Grub-Kranawetberg. The expectations of each model are listed in Table 4.

5.1. Model 1. Natural fire on non-human bone accumulation

This model involves a natural death assemblage, i.e., without any human interference, that was exposed to natural fire after its deposition. Random accumulation of bones with evenly distributed traces of burning would be expected (Costamagno et al., 2005), and in the case of adhering soft tissue, following Haynes (1991), it would be expected that the bones would exhibit localized damage due to smouldering of soft tissue. No human modifications such as cutmarks are expected on the bones. Similarly, any other evidence of human activity (e.g. lithics, personal ornaments) should be absent. Burning should occur *in situ*. Depending on when the burning occurred, different patterns would be expected, e.g. shortly after deposition when soft tissue was still attached to the bones or later when this was no longer the case. In the Grub-Kranawetberg bone accumulation bone assemblage there is evidence of human modifications in the form of butchery marks on innominate fragments of both mammoth and woolly rhinoceros. Human presence is further documented by other finds, including lithics, a piece of

Table 4
Models discussed in the text, their expectations, and evidence from Grub-Kranawetberg bone accumulation. Burn stages after Stiner et al. (1995).

Models: expectations	+/−	Grub-Kranawetberg bone accumulation evidence
1. Natural fire on non-human bone accumulation		
similar proportion of bone types in burned and unburned bones	+	• burned fragments: 37% spongy vs. 63% compact bone • unburned fragments: 39% spongy vs. 61% compact bone
localized burning damage on bones	+	• various colours of burned elements • black stains on further unburned bones • calcinated patches on blackened bones
no butchery marks	−	• butchery marks on pelvis of mammoth and rhinoceros
no other human activity (e.g. lithics, ornaments)	−	• lithics, perforated mollusk, red ochre
in situ burning	+	• spatial overlap of burning features and burned bones • presence of calcined bones • larger bone pieces broken but in original shape
no human impact on fire	−	• burning damage generally on lower surface of bones (bones were put on a already burning fire)
2. Natural fire, shortly after butchery		
bone assemblage consists of butchery waste	+/−	• meat-rich elements such as ribs and long bones present • 45% of faunal assemblage consists of teeth
similar proportion of bone types in burned and unburned bones	+	• burned fragments: 37% spongy vs. 63% compact bone • unburned fragments: 39% spongy vs. 61% compact bone
localized burning damage on bones	+	• various colours of burned elements • black stains on further unburned bones • calcinated patches on blackened bones
butchery marks probable	+	• butchery marks on pelvis of mammoth and rhinoceros
other human activity (e.g. lithics, ornaments)	+	• lithics, perforated mollusk, red ochre
in situ burning	+	• spatial overlap of burning features and burned bones • presence of calcined bones • larger bone pieces broken but in original shape
no human impact on fire	−	• burning damage generally on lower surface of bones (bones were put on a already burning fire)
3. Bone used as fuel		
spongy bone fragments dominate the burned bones	−	• in burned bones < 4 cm: 37% spongy bone
small size of burned fragments	+	• 99% of burned bones is< 4 cm
abundance of burned bone, but few or no charcoals	−	• abundant charcoal in bone accumulation and in campsite
easy burning bone is burned	−	• numerous teeth are burned • 39% of unburned bones are spongy
4. Bone marrow procurement		
abundance of marrow-rich burned bones	−	• burned teeth make up 34% of bones <4 cm
small size of burned fragments	+	• 99% of burned bones is <4 cm
bones dark brown due to indirect heat exposure	−	• various colours of burned elements • 39% of bones are black or white (burn stage 2–6)
no *in situ* burning	−	• spatial overlap of burning features and burned bones • presence of calcined bones • larger bone pieces broken but in original shape
5. Bone grease manufacture		
presence of fire-cracked rock and pitted stone anvils	−	• fire-cracked rock, stone anvils are absent
high fragmentation rate among spongy bones	+	• 96% of spongy bones is <4 cm
bones dark brown due to indirect heat exposure	−	• various colours of burned elements • 39% of bones are black or white (burn stage 2–6)
no *in situ* burning	−	• spatial overlap of burning features and burned bones • presence of calcined bones • larger bone pieces broken but in original shape
6. Roasting		
selection for meat-rich elements	−	• teeth are predominate in all elements (45%)
localized burning on parts of bones lacking meat	+/−	• localized burn damage on bones, but due to fragmentation no evidence on specific location
no *in situ* burning	−	• spatial overlap of burning features and burned bones • presence of calcined bones • larger bone pieces broken but in original shape
butchery marks probable	+	• butchery marks on pelvis of mammoth and rhinoceros
7. Ivory procurement		
many burned cranial elements, including teeth	+	• teeth fragments make up 34% of burned bones < 4 cm
small size of burned fragments	+	• 99% of burned bones is <4 cm
few other elements burned	−	• presence of burned ribs and long bone fragments
evidence of ivory processing	+	• worked ivory and half-fabricates present in campsite area
butchery marks unlikely	−	• butchery marks on pelvis of mammoth and rhinoceros
other human activity (e.g. lithics) likely	+	• lithics, perforated mollusk, red ochre
8. Waste removal		
similar proportion of bone types in burned and unburned bones	+	• burned fragments: 37% spongy vs. 63% compact bone • unburned fragments: 39% spongy vs. 61% compact bone
in situ burning	+	• spatial overlap of burning features and burned bones • presence of calcined bones • larger bone pieces broken but in original shape
human impact on fire	+	• burning damage generally on lower surface of bones (bones were put on a already burning fire)
other human activity (e.g. lithics, ornaments)	+	• lithics, perforated mollusk, red ochre

Table 4 (*continued*)

Models: expectations	+/−	Grub-Kranawetberg bone accumulation evidence
butchery marks probable	+	• butchery marks on pelvis of mammoth and rhinoceros
fuel other than bones (e.g. wood charcoal) present	+	• abundant charcoal in bone accumulation and in campsite
varying burning stages present	+	• all burn stages (0-6) represented
		• localized burning damage on bones

ochre, and one perforated shell. Spatial overlap of burned faunal elements and burned sediment and the occurrence of calcined remains indicate *in situ* burning. Localized burning damage on the bone fragments is evident as shown by bone fragments exhibiting black stains on otherwise unburned bones and calcinated patches occur on blackened bones. More importantly, traces of burning on the lower surface of some bones indicate that these were put on a burning fire by humans. In summary, although there is evidence for *in situ* burning and localized burning on the bones, these remains are clearly humanly modified as seen in the presence of butchery marks and other human activity including direct interaction with the fire. Therefore, Model 1 can be rejected.

5.2. Model 2. Natural fire after butchering by humans

In this model, fire occurred naturally and took place after abandonment of the site by humans. The expectations include what was described above for Model 1 except that signs of butchering on the faunal remains and possibly other evidence of human activity (e.g. lithics) are present. Tested against the Grub-Kranawetberg data, all expectations are met except that the presence of numerous dental remains is not typical for an assemblage that consists of the waste of butchery activities. Additionally, the bones with butchery marks do not show evidence of burning damage. Furthermore, the data suggest that at least some bones were put on a burning fire by humans. Model 2 can therefore also be rejected.

5.3. Model 3. Bones used as fuel

This model hypothesizes that humans accumulated bones to be used as fuel. Recent studies have established criteria to test if a bone assemblage results from the intentional use of bones as fuel (e.g. Théry-Parisot, 2002; Villa et al., 2002, 2004; Costamagno et al., 2005; Théry-Parisot et al., 2005; Clark and Ligouis, 2010). The most important argument is that spongy bone burns better than compact bone and in turn, the former should dominate the assemblage (Théry-Parisot, 2002; Villa et al., 2002, 2004; Théry-Parisot et al., 2005). Villa et al. (2004) compare the relative proportion of spongy vs. compact bone in a fragmented reindeer skeleton to their burning data. Although the relative proportion of spongy vs. compact bone for a mammoth skeleton is unknown and cannot be used in comparison to the Grub-Kranawetberg bone accumulation data, the basic principle that spongy bone burns better than compact bone holds. High frequencies of burned, small-sized (<2 cm) bone fragments are argued to be typical evidence of the use of bones as fuel. According to Théry-Parisot (2002) large quantities of burned bone, but only few pieces of wood charcoal characterize assemblages with evidence of bone use as fuel. Although fragments (<4 cm) make up the vast majority (99%) of the burned bone, it is evident that spongy bone fragments do not dominate the small burned bone fraction (Table 2). Additionally, unburned spongy bone is present. In fact, the spongy bone/compact bone ratio is similar for both the burned and the unburned part of the assemblage (Table 2). Numerous dental remains were burned, which argues against the intentional selection of the more combustible bone for fires. Large quantities of charcoal in the hearth structures within the campsite area indicate that the hearths were also fuelled with wood. Wood charcoal is also abundant everywhere in the archaeological horizon, as well as in the bone accumulation itself. Model 3 is therefore rejected.

5.4. Model 4. Bone marrow procurement

This model refers to the heating of long bones to facilitate the extraction of bone marrow. Binford (1981) describes several techniques for bone marrow extraction, only one of which includes the use of fire. In this case, defleshed bones are exposed to fire for only a short time, during which bones are turned frequently to prevent burning (Binford, 1981, 148). For this model to be accepted, one would expect a high percentage of marrow-rich bones among the burned elements, a high fragmentation rate among the burned bones (breakage to access the marrow), and limited burning damage. In Binford's (1981) model bones are broken to extract marrow after heating occurred and discarded afterwards. This implicates secondary deposition of the burned fragments. The Grub-Kranawetberg assemblage displays none of these expectations other that the high fragmentation of burned elements. Therefore, it seems unlikely that bone marrow procurement was the driving force behind the accumulation of the assemblage.

5.5. Model 5. Bone grease manufacture

Bone grease manufacture involves cooking in water previously fragmented grease-rich bone portions (e.g. articular ends of long bones, vertebrae) in a container and skimming off the fat that rises to the surface (Binford, 1978). As recently described by Fladerer et al. (2010) this method might be especially useful for proboscidian bones because bone marrow is stored mainly in cancellous bone and not in big medullary cavities (like in ungulates) that can be accessed by fracturing. Following Binford (1978), archaeological evidence for bone grease procurement includes: stone anvils to break bones prior to cooking, fire-cracked rocks indicative of a stone boiling technique, and highly fragmented spongy bones. The boiling method results in limited burning damage on the bones (Stages 0–1 after Stiner et al., 1995). Deposition of the bones will either be in the "container" (e.g. a pit) or secondary deposition elsewhere. In the case of Grub-Kranawetberg bone accumulation, none of the expectations for bone grease procurement are met. Bones show a large variety of burning damage, and spongy bone does not dominate the burned bone assemblage. There are no fire-cracked rocks pitted stone anvils, nor pits, and all evidence speaks against secondary deposition.

5.6. Model 6. Roasting

This model explains the burning of bones through the process of roasting meat. The expectations include intentional selection of meat-rich elements and that localized burn marks are present on those parts of the bones lacking meat and other soft tissue at the time of roasting. After roasting, the bone is defleshed and discarded (Buikstra and Swegle, 1989; Cain, 2005). Therefore, one does not expect evidence of *in situ* burning. In Grub-Kranawetberg, meat-rich parts such as ribs as well as meat-poor parts like ivory and molars are present. There is no evidence of selection for meat-rich parts. There is evidence of localized burning on the bones themselves. However, the high fragmentation rate makes it impossible to ascertain whether the burning took place on the parts of the bones lacking meat. There is evidence for *in situ* burning, which is in disagreement with the model expectations of roasting.

5.7. Model 7. Ivory procurement

This model describes the burning of the cranium to extract the tusk(s). Fire is used to burn soft tissue surrounding the premaxilla in fresh carcasses. For this model to be true, many cranial fragments including ivory and maxillary molars would be expected, but few other elements, within the burned remains and a high fragmentation rate of burned elements. Ivory should be partly burned. Moreover, evidence of ivory processing in the site can be expected and other human activity (as shown by lithics, and personal ornaments) at the site is probable. Butchery marks are unlikely to occur as the goal of the accumulation would be raw material acquisition and not primarily subsistence. Most of the expectations of this ivory procurement model are in line with what is found at the site. There is a high fragmentation rate of burned elements, which include many cranial fragments and ivory. Human activity is indicated by the presence of a small archaeological assemblage. The importance of ivory as raw material for the manufacture of tools and personal adornments is provided by extensive evidence of ivory working in AH 4 of the nearby campsite area that is contemporaneous with the bone accumulation. Indicated by the presence of both worked ivory (ca. 230 beads, ca. 70 awls and awl fragments) as well as half-fabricates. However, the occurrence of burned meat-rich elements and butchery marks, as well as the presence of unburned tusks is not consistent with the expectations of Model 7. Additionally, preliminary data on worked ivory and half-fabricates of AH 4 of the nearby campsite area shows a low incidence of burning damage. The few cases of burning can easily be explained by accidental burning. Therefore, it seems more likely that ivory was burned after it was discarded from ivory working.

5.8. Model 8. Waste removal

This model describes a strategy involving the burning of waste from various sources (e.g. subsistence, tool production) in order to clean the living space or for hygienic reasons (see Cain, 2005). In general, the same proportion of bone types (spongy/compact) in the burned and unburned categories is expected, since a waste removal fire should affect all bones in the waste dump that is burned (Costamagno et al., 2005). Because the goal of the fire is waste removal, no further transportation of the burned elements is expected, so evidence for *in situ* burning should be found. Furthermore, traces of human activity as well as lithics and other material culture remains are likely. As in the waste removal model bones are not burned as fuel one can expect that bones were not burned completely. Similarly, different proximity to the core of the fire should result in a variety of burn stages. Because bones are not the primary means of fuel, other sources of fuel such as wood are likely to occur. When looking at the Grub-Kranawetberg data, a complete overlap with the expectations of this model can be seen. The evidence for human activity, *in situ* burning, human involvement in the burning of bones, the variety of burn stages, the localized burning damage, the presence of charcoal, and the similar proportion of bone types in the burned and unburned remains, are all in line with the burning of waste. Thus, the role of fire in the Grub-Kranawetberg bone accumulation is best explained as a waste removal strategy.

6. Discussion and implications

Concerning the Grub-Kranawetberg bone accumulation, Model 8 is the most parsimonious, as all expectations of the model are met, indicating the use of fire as a waste removal strategy. In this case waste removal is the last stage of human interaction with these bones. However, prior to being waste these faunal remains would have had a different function or functions. To a certain extent, the reason for the accumulation of these remains by humans is likely to be reflected in the composition of the bone deposit.

Next to those of Model 8, the expectations of Models 2 and 7 are almost all met. The presence of meat-rich elements and butchery marks suggest that part of the remains were gathered during subsistence practices. The abundance of ivory suggests the additional gathering of these mammoth remains for ivory working. This fits with the evidence of extensive ivory working at the nearby campsite area. Current results indicate that mammoth bone accumulations do not necessarily solely result from subsistence practices but that raw material acquisition seems to have been important as well.

In this study the mammoth bone accumulation has been treated as one temporal unit, but it could be a time-averaged accumulation. The assemblage could have been accumulated over a longer time and represent two or more events. For example, in a two event-scenario, the first phase consists of the accumulation of bones, mainly mammoth ribs and dental remains, which were then burned *in situ*, by humans. A second phase includes the accumulation of butchered remains of multiple species that were left unburned. However, several lines of evidence suggest that such a scenario is not likely. Spatially, there is no separation between the remains of different taxa as well as between the burned and unburned assemblages. When looking at the small fragments, the spongy/compact bone ratio in the burned and unburned fraction is very similar. The variety of burning damage and its localized distribution on the bones suggests that some bones were less exposed to fire than others. The presence of unburned remains is in agreement with this conclusion. Minimal weathering and absence of carnivore gnaw marks on the bones together with the preservation of lenses of ashy sediment suggest that bones were buried quickly. Taking the evidence of the faunal remains and the lenses of burned sediment as well as their spatial location into account, the evidence for time averaging is not extensive, but it cannot be excluded at this point. Concerning the non-faunal remains, it cannot be determined whether they are part of the deposited waste, related to accidental loss or to other activities at the location.

When comparing the Grub-Kranawetberg data to other Gravettian sites in the region the high variability between mammoth bone accumulations both in structure and composition is striking. For example there are differences in abundance of mammoth remains both in MNIs and skeletal element frequencies (e.g. Soffer, 1985, 2003; Soffer et al., 2001; Bosch, 2009; Brugère and Fontana, 2009). Interpretations concerning mammoth bone accumulations are likewise diverse. The sites of Krakow Spadzista Street B (Poland) and Milovice I-G (Czech Republic) have been interpreted as butchery sites (Svoboda et al., 2005), whereas other areas in the Milovice I site complex are indicative of acquisition of ivory as a raw material (Brugère and Fontana, 2009).

Few mammoth bone accumulations in the middle Danube region show traces of burning. The recent studied faunal assemblages at Milovice I show no traces of fire (except for one mammoth rib, Brugère and Fontana, 2009), however there is evidence of hearths at the site (e.g. Péan, 2001). Mammoth bone accumulations with traces of burning show a differential use of fire. The mammoth bone accumulation at Dolní Věstonice II (Svoboda, 1991), is located in a gully approximately 120 m west of the main camp site area.

Similar to Grub-Kranawetberg bone accumulation, this bone accumulation shows evidence of human activity indicated by butchery marks on faunal remains as well as by few lithics and one pierced mollusc. Burning is evident from patches of charcoal, but to the authors' knowledge, no information on burning traces on the faunal remains is published. The composition of the mammoth remains differs from Grub-Kranawetberg bone accumulation in that long bones and complete ribs are frequent whereas innominates and crania are less numerous. At Předmostí I-06, the lower archaeological horizon contains a bone accumulation dominated (ca. 90%) by mammoth remains (Svoboda, 2008; Beresford-Jones et al., 2010). There is abundant evidence of human impact like cutmarks on the faunal remains. About half of the bones (49.3%) are either carbonized or calcined (Beresford-Jones et al., 2010). The mammoth bone accumulation at Krakow Spadzista Street B contains only a few carbonized bones that are smaller than 2 cm, which is interpreted by Wojtal and Sobczyk (2005) as evidence of the use of bone as fuel.

There are other sites in the middle Danube region, that are not classified as mammoth bone accumulations, but that comprise of numerous burned mammoth remains. A good example is the site of Krems-Wachtberg (excavations 2005–2010; Fladerer et al., 2010).

Beresford-Jones et al. (2010) report that based on flotation data from Předmostí I-06 and Dolní Věstonice II, fires were fuelled with either wood or bone depending on type of human activity and duration of site occupation. They argue for the use of wood at base camp type sites, and the use of bone at short-term occupation sites with specialized activities. That fire was also used for different purposes on intra-site level is shown by data on fire for Grub-Kranawetberg. Fire was used for waste removal at the bone accumulation, whereas wood-fuelled hearths were uncovered at the contemporaneous AH 4 of the campsite area. The variability in the use of fire makes it important not only to gain more information on the role of fire at different sites, but also to study the whole site complexes rather than selected areas such as bone accumulations or hearth structures (e.g. Djindjian and Iakovleva, 2010; Iakovleva et al., 2010) to get a better view on the importance of fire and its different applications in this time and region.

Current evidence of waste removal at Grub-Kranawetberg bone accumulation adds to the discussion of the duration of site occupation in the Gravettian settlement system. For the Gravettian of the middle Danube region the duration of occupation at some of the large open-air sites in southern Moravia (e.g. Pavlov I, Dolní Věstonice I and II) has been discussed since a long time. Some scholars have suggested a settlement system based on long-term settlements (e.g. Absolon, 1938, cited after Verpoorte, 2001) while others have argued for repeated occupation of the same central site locations and significant time averaging in these sites (e.g. Verpoorte, 2001). The presence of waste removal strategies suggests that a site was inhabited long enough to make site maintenance strategies beneficial. This is in good agreement with, first, the presence of heath pits and other pits and features (Antl-Weiser et al., 1997, 2010; Antl and Fladerer, 2004; Antl-Weiser, 2008), and, second, the indirect evidence for dwelling structures based on the spatial analysis of finds and features (Nigst, 2003, 2004a, 2004b, 2006) in AH 4 of the adjacent campsite. Both indicate substantial investments in the site infrastructure consistent with a relatively long occupation time (e.g. Binford, 1990; see also Smith, 2003). Similarly, very short-term camps would not be expected to show substantial investment in site maintenance, as people move on to the next location. Therefore, longer site use has implications on settlement systems, the human landscape use and human life-ways. The findings (waste removal by burning) contribute to the current hypothesis that some sites have been used for long enough duration to make investment in site maintenance activities beneficial.

7. Conclusions

With regard to analytical methods, there are difficulties attributing dental fragments and ivory fragments to the burn stages defined by Stiner et al. (1995). Experimental work on burning damage on ivory is necessary in order to understand the effects of burning temperature on the structure and colour of ivory in comparison to bone. Although much is known about burned bone from medium to large animals in archaeological contexts, less is known about burning of proboscidean remains. Evidence on the spongy/compact bone ratio in a single mammal skeleton has been used as a comparison with unidentified burned fragments to infer if this reflects natural bone type proportions or if certain bone types were selected for by the burning agent (e.g. humans, natural causes) (Villa et al., 2004). Mammoth bones are composed differently than bones of most other mammals (Haynes, 1991). Therefore, a similar study on bone type proportions of proboscideans would be extremely useful when studying the role of fire in mammoth bone accumulations. The results compared to the bone type ratio of a burned mammoth bone assemblage will help to infer the impact of fire on mammoth bones. Such experimental studies would be valuable for future research on burned mammoth remains from the numerous mammoth bone accumulation sites in the middle Danube region and elsewhere in Europe.

Current results show that humans are clearly the main contributor for the accumulation of the mammoth bone deposit at Grub-Kranawetberg. The bone accumulation is composed of waste produced by the people occupying the nearby campsite. This is demonstrated by the suggested contemporaneity of AH 4 of the campsite area with the bone accumulation. The most parsimonious explanation for the role of fire in the bone accumulation is that it was used as a waste removal strategy. Traces of the use of these faunal remains prior to burning are evident and twofold: (1) meat-rich elements are likely the result of subsistence practices, and (2) ivory and additional remains, such as cranial and dental fragments, likely result from procurement of ivory for the manufacture of tools and personal ornaments. Therefore, it is clear that although subsistence is an important part of man–mammoth interaction in general, raw material acquisition certainly also played a role in the middle Danube region during the Gravettian.

Variability in the composition of mammoth bone accumulations as well as the use of fire at different occasions in this region is striking. As illustrated with the example of Grub-Kranawetberg bone accumulation, it is important to study site complexes rather than only features such as bone accumulations or hearths in order to gain better insight on Palaeolithic human behaviour. In the Gravettian people occupying the middle Danube region show a large variability in behaviour seen on both inter- and intra-site scale. The practice of waste removal indicates that Grub-Kranawetberg was inhabited long enough to make this kind of site maintenance beneficial. Therefore, these findings contribute to the discussion of the duration of site occupation in the Gravettian settlement system of the middle Danube region.

Author contributions

MDB, FAF, PRN, WAW designed research, MDB, FAF, PRN performed research, MDB, FAF, PRN, and WAW analyzed data, MDB and PRN wrote the paper. All materials are stored in the Department of Prehistory, Natural History Museum Vienna, Austria.

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