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Paleolithic occupations in the Lahn Valley of Central Germany: New dating and ZooMS results from Wildscheuer, Wildweiberlei, and Wildhaus

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ABSTRACT

There is limited evidence of repeated occupations by Neanderthals or modern humans in the part of Central Germany that roughly corresponds to the present-day Federal State of Hesse. The Lahn Valley located in the southwestern sector of this region is an exception. Based on early excavations of a series of now destroyed sites, the Lahn Valley has yielded sparse evidence of Neanderthal occupation from the Middle Paleolithic and has produced a more substantive Upper Paleolithic sequence including the Aurignacian, Gravettian, and Magdalenian, as reflected in the lithic and organic material culture. The present study attempted (i) to gain greater understanding of the chronology and use of animals by humans in the Wildscheuer cave, and (ii) to contextualize the Lahn Valley in the broader Paleolithic landscape of Central Europe. We targeted over a dozen samples consisting of faunal remains with fresh fractures, osseous artifacts, and human remains that derive from the cave site. The results confirm previous findings with the dates concentrated around the middle-to-late Aurignacian. These data suggest that, unlike cave-rich areas to the south (i.e. the Swabian Jura), the Wildscheuer was occupied neither immediately nor consistently when modern humans arrived in the region but also that multiple occupational events took place during the remainder of the Upper Paleolithic. This aligns with the ursid remains from the nearby Wildweiberlei, which predate the human occupation. Conversely, our dating efforts did not find evidence of substantial Gravettian or Magdalenian occupation in Wildscheuer, although this may also be a result of our modest sample size. In addition, ZooMS analysis revealed one of the first evidence of the use of wooly rhinoceros in the production of osseous artifacts such as smoothers. This study calls for renewed attention to the Lahn Valley as archaeometric methods that may be applied to legacy materials improve, and in tandem with our greater understanding of the early to late Upper Paleolithic in Central Europe on a regional to sub-regional scale.

1. Introduction

The Paleolithic record of Central Europe is well-documented thanks to a long tradition of research (Bosinski 1967, Hahn 1977, Jochim 1998, Svoboda et al. 2013). Despite this legacy, archaeologists have yet to fully understand what kind of settlement dynamics were at play on this mid-latitude Paleolithic landscape. Most notably – and despite this long history of investigation – the evidence for hominin land-use is very unevenly distributed. In the part of Central Germany corresponding to the present-day Federal State of Hesse, for instance, actual evidence of human presence during the Middle and Late Pleistocene is rather sparse. While both Neanderthals and *Homo sapiens* clearly were present in the region (Fiedler 1990, 1994, 2006), recent survey efforts confirm the overall sparsity in the relation to the Late Paleolithic at least (Riede 2016, Sauer et al. 2018). The Lahn Valley located in the south-western sector of the German Federal State of Hesse is an exception, however, as it has yielded key cave sites – long since excavated and destroyed, unfortunately – that provide rarified insights into the lifeways of

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Neanderthals and modern humans. Given the valley's singular importance, we revisited the Wildscheuer complex through redating of legacy faunal and human remains as well as the ZooMS analysis of osseous artifacts obtained during excavations in 20th centuries (von Cohausen 1874, 1882, Mandera 1954) with the aim to complement previous studies and to better understand the past settlement dynamics in the region.

The Lahn Valley is well-studied for its historical and archaeological importance, but merits renewed attention for multiple reasons: 1) Archaeological sites dating to the Paleolithic in the present-day Federal State of Hesse remain relatively scarce and the Lahn Valley therefore remains an important empirical anchor point in Central Germany. 2) While the cave complex itself is destroyed, past excavations have documented a stratified sequence of archaeological remains including ample organic remains such that novel archaeometric methods can potentially shed new light on these sites. We here contextualize the sites chronologically, reconsider some of the osseous artifacts from Wildscheuer, and revisit the documentation of the past excavations and the stratigraphic sequence in the context of pertinent historical archives. In so doing, we explore whether renewed dating changes the chronological understanding of the Lahn Valley Palaeolithic. As our dating campaign also targets some of the human remains originally retrieved from the cave, we assess whether these belong to the Paleolithic or to more recent periods. With an improved understanding of the Lahn Valley chronology in hand, we reflect on the Paleolithic occupation dynamics in this area and compare it to neighboring areas. Finally, we assess to what degree animal-human interactions as revealed by our ZooMS analysis align with or differ from conventional zooarchaeological identification efforts. In sum, these new data provide improved chronological constraints on the hominin occupation of the Lahn Valley caves, suggesting that their use concentrated on the earlier part of the Upper Paleolithic.

2. The Lahn Valley caves and their research history

The Lahn Valley rests on a karstic limestone substrate and the River of Lahn runs into the Rhine River running westward, making it one of the tributaries. The Wildscheuer cave complex (UTM 32U: E 437986 N 5585714) was located in a limestone outcrop near the town of Runkel-Steeden. With a main entrance 6 m wide and 7 m high as well as a main chamber that run 18 m deep, the Wildscheuer was once the largest cave in the region (Fig. 1). It was situated uphill at ~ 190–250 m asl presumably providing good views of the riverine floodplain below (Terberger 1993). Two nearby cave-sites were also excavated alongside Wildscheuer: Wildhaus and Wildweiberlei. Wildhaus, a small niche close to the Wildscheuer yielded mostly human remains (von Cohausen 1879, Schaaffhausen 1879). Wildweiberlei is located outside of the Leerbach Gorge roughly 15 km away (von Cohausen 1874, Terberger 1993).

The sites were initially excavated by Karl August von Cohausen in 1874 (von Cohausen 1874, von Cohausen 1879, von Cohausen 1882). They were later revisited by other researchers until they were completely destroyed in the 1950s for limestone quarrying and to make way for a railroad line. Notably, von Cohausen was one of the first to document the association between lithics and the extinct mammoth in Germany, contributing to the debate surrounding the antiquity of humans and the Earth. In Germany at least, the data from and debate around the Lahn Valley caves helped to foster the emergence of prehistoric archaeology as a scientific discipline. Mandera (1954) was the last archaeologist to systematically investigate the caves. He diligently documented what remained of the stratigraphic sequence. In the process, he was able to document important profiles, especially in front of the cave entrance, while the interior of the cave had already been largely cleared out by the older excavations. (Figs. 2, 3 / Table 1).

Decades after the removal of the cave complex by dynamite,

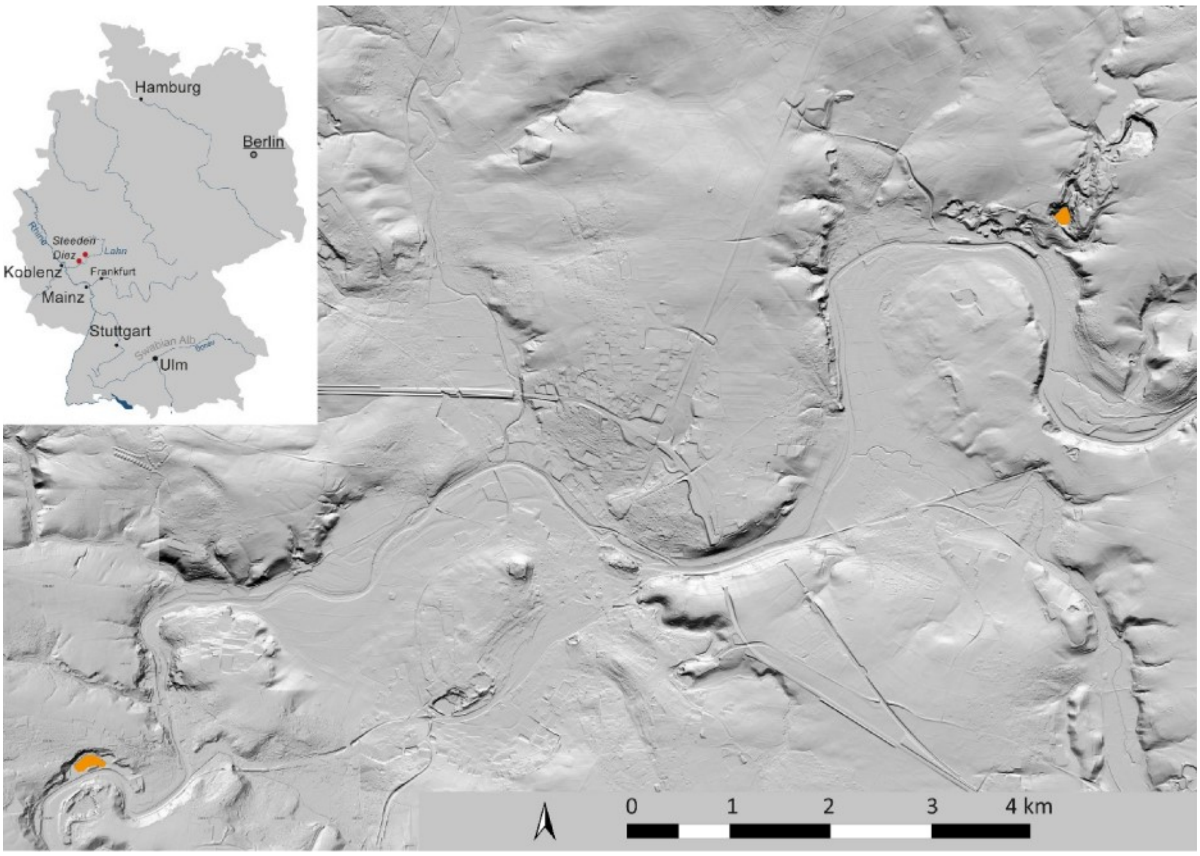

Fig. 1. The Lahn Valley in Central Germany. On the left, the yellow area marks the previous location of Wildweiberlei, on the right, yellow area marks the location of Wildscheuer and Wildhaus.

Fig. 2. A drawing created by K. A. v. Cohausen of the Wildscheuer cave shows the cross section of the cave (left) and a photo from 1954 of the cave shortly before it was blown up shows the entrance (right).

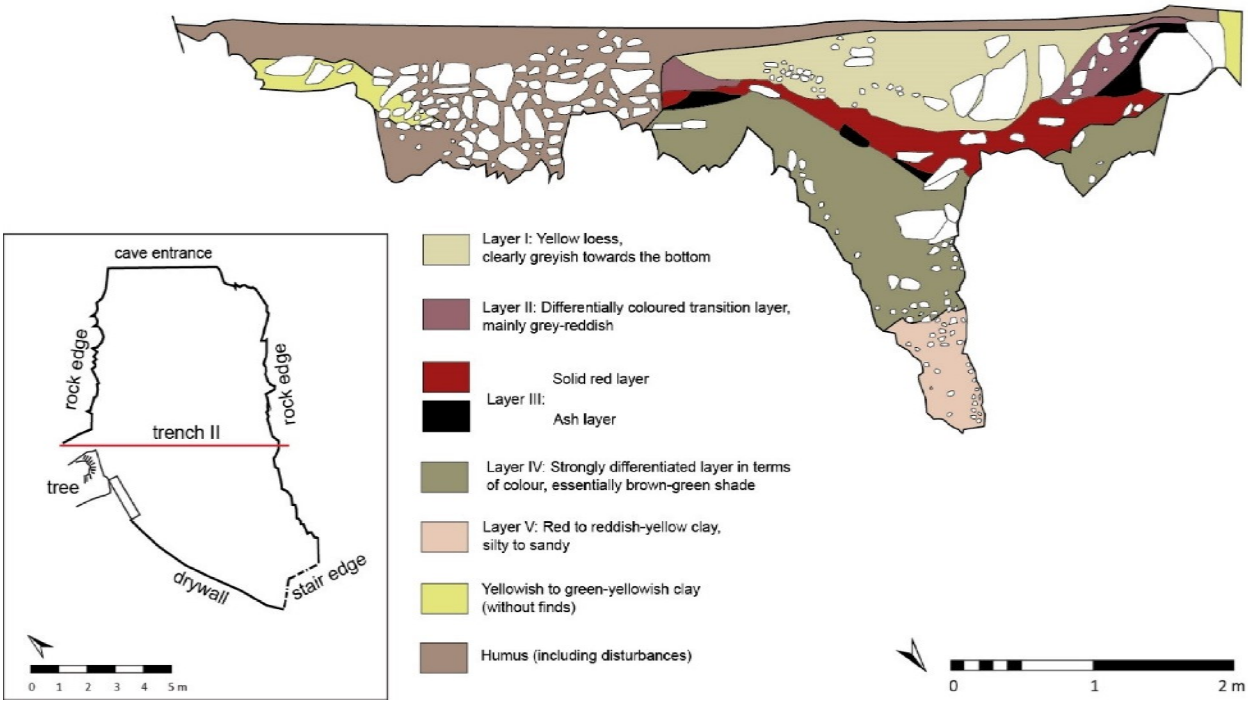

Fig. 3. The stratigraphy of the Wildscheuer cave in front of its entrance as documented by Mandera from the southern profile of trench section II. Modified from the original drawings by Mandera (1954:39).

Table 1
Layers and some noted associated artifacts from Wildscheuer (Terberger 1993).

Layer	Approximate thickness (m)	Notable Finds
Humus	0.5	Neolithic and younger material
Wildscheuer V (Magdalenian)	0.6	Perforated fox teeth, foreground of the cave was covered with slates
Wildscheuer IV (Gravettian)	0.6	Decorated bird bone; ivory artifacts
Wildscheuer III (Aurignacian)	0.3	Possible use of ochre, multiple fireplaces, personal ivory ornament as well as perforated animal teeth and stone pendants.
Wildscheuer II	1.15	Red ochre (hematite)
Wildscheuer I	0.9	Flakes from Kieselschiefer

Terberger's (1993) comprehensive study reviewed the excavated materials from Wildscheuer and the neighboring sites including their research history, stratigraphy, and lithic assemblages from the excavations of the late 1800s to the mid-1900s. Her study provided detailed background information of the sites, a description of the past excavations and, importantly, the correlations of the stratigraphies described by various excavators. Regarding the lithic finds, Terberger demonstrated a marked contrast between the Middle and Upper Paleolithic assemblages. Others have since revisited the Upper Paleolithic tools, which were dominated by endscrapers and burins (Pastoors and Tafelmaier 2012, Terberger 1993). The abundant animal and somewhat more modest human remains from the Lahn Valley caves have also been studied by multiple researchers, including Schaaffhausen's (1874) original description and Street's re-analysis, which accompany the study of Terberger (1993). Turner et al. (2000) were able to reject the presence of Neanderthal fossils at the site and correctly identified the cranial remains to the otherwise abundant cave bears (*Ursus spelaeus*) instead. Turner (2004) later interrogated the assemblages from a taphonomic perspective with a particular focus on the Middle Paleolithic. Previous dating studies focused on contextualizing the Paleolithic chronology of the Lahn Valley on a broader regional scale of Germany and Central Europe (Pettitt et al. 1998, Street and Terberger 2004); our study aligns with these efforts.

3. Materials and methods

From the collection at the Sammlung Nassauische Altertümer in Wiesbaden, we selected specimens from Wildscheuer (WS), Wildweiberlei (WW), and Wildhaus (WH) for AMS dating. A total of 17 samples consists of faunal remains with fresh fractures that indicate prehistoric breakage, osseous artifacts (an antler fragment with engraved fish motif, an antler hammer, and a smoother-like artifact [supplementary material]), as well as human remains. Except for one specimen, the samples lacked stratigraphic and spatial information; in advance of sample extraction, the objects were visually inspected, photographed, and 3D-scanned using an Arctec Space Spider.

Samples amounting to ~0.5–1 g were then sent to the AMS ^{14}C Dating Laboratory at Aarhus University for further treatment and processing. FTIR analysis was conducted to ensure that no contamination such as curatorial adhesives affected the analysis. In total, 13 fragments yielded sufficient collagen and dates with an adequate C:N ratio (Table 2). None of three osseous artifacts could be dated due to insufficient collagen level. All dates were calibrated using IntCal20 (Reimer et al. 2020) implemented in OxCal v4.4.4.

ZooMS analysis was carried out on 12 samples, including nine samples whose dates were obtained as part of this study and another three whose collagen level was not enough for AMS dating but proved sufficient for ZooMS (Table 3). Collagen was either extracted directly from bone chips or from the remaining lyophilized protein extracted for radiocarbon dating. ZooMS analysis of bone chips followed previously published protocols (Welker et al. 2016, Brown et al. 2020). Briefly, bone chips were demineralized in 0.5 M HCl and rinsed in 50 mM ammonium bicarbonate. The demineralized bone chips were then gelatinized at 65 °C for one hour. ZooMS analysis carried out with lyophilized collagen followed the protocol of Coutu et al. (2016). Less than 1 mg of collagen was eluted in 50 µl of 50 mM ammonium bicarbonate and gelatinized at 65 °C for one hour.

After gelatinization, each sample was then treated with 0.4 µg trypsin (Thermo Scientific Pierce ™ Trypsin Protease). Enzymatic digestion took place at 37 °C for 18 h. The incubated samples were concentrated and desalted using C18 ZipTips (Thermo Scientific Pierce™ C18 Tips) and eluted in a final solution of 50 µl of 50 % acetonitrile and 0.1 % TFA. 0.5 µl of the resulting solution was mixed with 0.5 µl of α cyano-4-hydroxycinnamic acid solution (10 mg/mL in 50 % acetonitrile and 0.1 % trifluoroacetic acid) and allowed to crystallize.

Prepared ZooMS samples were measured using a Bruker Autoflex LRF MALDI-TOF MS in the Archaeo- and Paleoproteomics Laboratory at the University of Tübingen. The resulting spectra were peak-picked with a signal to noise ratio of 3.5 after baseline correction, smoothing, and deisotoping with the default parameters and analyzed with flexAnalysis 3.4 (Bruker Daltonics) and mMass software (Strohalm et al. 2008). The spectra were compared against a reference library of known peptide markers (Buckley et al. 2009, 2010, Buckley and Kansa 2011, Welker et al. 2016) following the guidelines in Brown et al. (2021). The taxon is determined on the family/genus level based on the protein makeup and later identified to possible fauna written as cf., which were present in Central Europe during the Late Pleistocene.

4. Results

Some of the artefacts sampled did not, despite due pretreatment, yield satisfactory C:N ratios; they were deemed unsuitable for dating. Other sampled osseous artifacts, including the unusual fish-motif antler piece and antler hammer, also did not yield sufficient collagen. The collagen yield across all samples ranged between 0.6–6.2 %. Some of the

Table 2
Radiocarbon dating results for n = 13 samples from Wildscheuer, Wildweiberlei, and Wildhaus with adequate C:N ratio. Sample IDs correspond to numbers in Fig. 4.

Site	Year/ context	Species	Element	Sample ID	Dating ID #	14C age (BP)		% yield	%C	$\delta^{13}C$	$\delta^{15}N$	C:N ratio	Calibrated age range (calBP) 94.5 %	
													From	To
Wildscheuer	1953	ibex	humerus	42,171	AAR-34417	33,982	257	3.1	41.4	−19.5	5.5	3.3	39,759	38,045
Wildscheuer		horse	metapodial	42,175	AAR-34421	32,838	271	1.0	22.5	−20.6	5.2	3.3	38,445	36,469
Wildscheuer		megafauna	rib	42,168	AAR-34414	31,293	244	4.1	33.1	−20.2	5.2	3.4	36,196	35,229
Wildscheuer	1905 / Loess layer	reindeer	antler/ cranium	42,174	AAR-34420	23,299	242	3.6	43.5	−18.8	2.3	3.4	27,869	27,191
Wildscheuer	1874	red deer	metatarsus	42,169	AAR-34415	5510	41	0.9	26.8	–23.4	5.8	3.2	6397	6211
Wildscheuer	1874	red deer	metacarpal	42,170	AAR-34416	5452	37	6.2	39.1	–23.5	6.1	3.3	6308	6190
Wildscheuer	1874	cervid	metacarpal	42,176	AAR-34422	5684	36	4.4	40.8	−21.7	7.5	3.3	6605	6352
Wildscheuer		human	humerus	42,160	AAR-34406	4432	38	4.3	24.1	−20.3	11.4	3.1	5280	4872
Wildscheuer		human	humerus	42,161	AAR-34407	4536	37	0.6	19.7	−20.4	10.2	3.2	5316	5050
Wildhaus		human	radius	42,162	AAR-34408	2183	33	11.0	43.2	−18.8	15.5	7.3	2405	2160
Wildhaus		human	humerus	42,163	AAR-34409	2314	32	4.6	44.3	−19.0	15.5	7.9	2319	2067
Wildweiberlei		bear	cranium/ parietal	42,172	AAR-34418	36,205	319	4.0	43.0	−21.9	3.8	3.3	41,846	40,728
Wildweiberlei	D/Red-yellow layer	bear	mandible	42,173	AAR-34419	36,781	354	1.2	31.7	−21.1	1.2	3.2	42,114	41,174

Table 3
The ZooMS results of samples from Wildscheuer and Wildweiberlei.

Sample ID	Dating ID #	initial faunal identification	Bone/ Collagen	ZooMS ID	COL1α1 508 – 519	COL1α2 978 – 990	COL1α2 978 – 990	COL1α2 484 – 498	COL1α2 502 – 519	COL1α2 292 – 309	COL1α2 793 – 816	COL1α2 454 – 483	COL1α1 586 – 618	COL1α1 586 – 618	COL1α2 757 – 789	COL1α2 757 – 789
42,164	NA	antler – cervid	Collagen	Cervidae/ Gazella/Saiga	1105.6	1180.7	1196.7	1427.8	1550.9	1648.9	2131.1		2883.5	2899.5		3033.6
42,165	NA	megafauna	Bone	Rhinocerotidae	1105.6	1182.6	1198.6	1453.8	1550.9	1648.9	2145.2	2792.5	2869.6	2885.5		2999.6
42,166	NA	antler – reindeer	Bone	Reindeer	1105.6	1150.7	1166.7	1427.8	1580.9	1648.9	2131.2		2883.6	2899.6		3093.7
42,168	AAR-34414	megafauna	Bone	Rhinocerotidae	1105.6	1182.7	1198.7	1453.8	1550.8		2145.2		2869.5			
42,169	AAR-34415	red deer	Bone	Cervidae/ Gazella/Saiga	1105.6	1180.7	1196.7	1427.8	1550.8	1648.9	2131.1	2792.2	2883.5	2899.5		3033.6
42,170	AAR-34416	red deer	Collagen	Cervidae/ Gazella/Saiga	1105.6			1427.7	1550.7		2131.1		2883.3	2899.3		3033.5
42,171	AAR-34417	ibex	Collagen	Ovis	1105.5			1427.7	1580.6	1648.8	2131		2883.4			3033.2
42,174	AAR-34420	reindeer	Collagen	Reindeer	1105.5			1427.6	1580.7	1648.7	2131					
42,175	AAR-34421	Equus sp.	Bone	Equidae	1105.5	1182.5	1198.5	1427.7	1550.7		2145.2		2883.4	2899.4		2999.5
42,172	AAR-34418	cervid	Collagen	Ursidae	1105.5		1233.6	1453.6			2163		2853.3		2957.2	
42,173	AAR-34419	ungulate	Bone	Ursidae	1105.6		1233.6	1453.7	1566.7		2163.1		2853.4	2869.4	2957.4	
42,176	AAR-34422	cervid	Bone	Ovis	1105.6	1180.6	1196.6	1427.7	1580.7		2131.1		2883.4	2899.3		3033.4

larger yields derive from materials that resulted in more recent dates. Osseous artifacts including a fragment of a smoother-like artifact, produced sufficient collagen for ZooMS, but not for ^{14}C dating despite our pretreatment efforts.

4.1. Dates

Among our samples, three clusters of dates emerged, two belonging to the early Upper Paleolithic with a relatively wide range that falls between the Aurignacian and the Gravettian and the third falling into the Neolithic and Iron Age (Fig. 4). The human remains from WS date to between 5316 and 4872 calBP, which puts them squarely in the Neolithic. There are also three cervid remains that date to this period, albeit with a 1000-year gap (6605–6190 calBP) vis-à-vis the human remains, making this a separate deposition event. This in turn indicates that there was a Neolithic component in WS with multiple activity phases. Other human remains from WH date to 2405–2067 calBP (i.e. the Iron Age) so none of these human remains relate to the earlier Middle and Upper Paleolithic occupations of the cave (Fig. 5).

The earliest Upper Paleolithic dates from WS range between 33,980 ± 260 to 31,290 ± 240 BP (39,760–35,230 calBP). Two dates from WW are slightly older than WS (42,110–40,730 calBP). One sample of WS is a rib fragment from a megafauna, either wooly rhinoceros or mammoth, and exhibits several cutmarks and a series of notch marks along the long edge of the rib. It dates to 36,200–35,230 calBP (AAR-33414), making it one of the oldest in this sampling pool besides those of WW. In addition, two samples that derive from herbivores (horse and small bovid) fall in a similar range, i.e., that of the late Aurignacian. They also align with previously published dates from WS.

A reindeer cranium with an antler from the supposed loess layer of WS dates to 27,870–27,190 calBP and points to the Gravettian occupation, which has also been identified in previous dating attempts by Pettitt et al. (1998) and Street and Terberger (2004). Magdalenian occupation in WS is not reflected in our samples.

4.2. Zooarchaeology by mass spectrometry (ZooMS)

ZooMS analysis helped verify some of the morphological determinations on the level of family or genus and to identify the animals that were exploited for osseous artifacts (Table 3). Samples from WW, which yielded the oldest dates in our sampling pool, derive from ursids initially identified falsely as ungulates. Based on other identifiable remains and knowing the common bear species in Central Europe, they are likely cave bears (*Ursus spelaeus*). Importantly, these specimens predate deposits that are associated with human activities in WS.

In addition, two samples which were initially identified as small bovid were proteometrically determined to be European mouflon (*Ovis musimon* or *O. aries musimon*) or chamois (*Rupicapra rupicapra*). Currently, this is the only evidence of these small bovids at the site. One of the most intriguing insight related to the two megafaunal ribs: one is a modified bone with cutmarks as described above while the other represents a smoother-like artifact. Both have been identified as wooly rhinoceros, which remains relatively rare both on the local level and more broadly as a raw material for osseous technology in the Paleolithic.

5. Discussion

Our new dating efforts largely confirm the models proposed in previous studies that focused on the Lahn Valley (Table 4). Our results are in alignment with the work of Pettitt et al. (1998) and Street (2011), with most of the dates relating to the Aurignacian occupation. Specifically, these dates suggest an occupation peak between 39,760–35,229 calBP (36,781–31,293 BP), which overlaps with the previous dates of 41,531–31,530 calBP (34,200–28,340 BP; Pettitt et al. 1999). These traces of Upper Paleolithic occupation thus fall squarely in the range of the Aurignacian (Pettitt et al. 1998). Although our samples were not

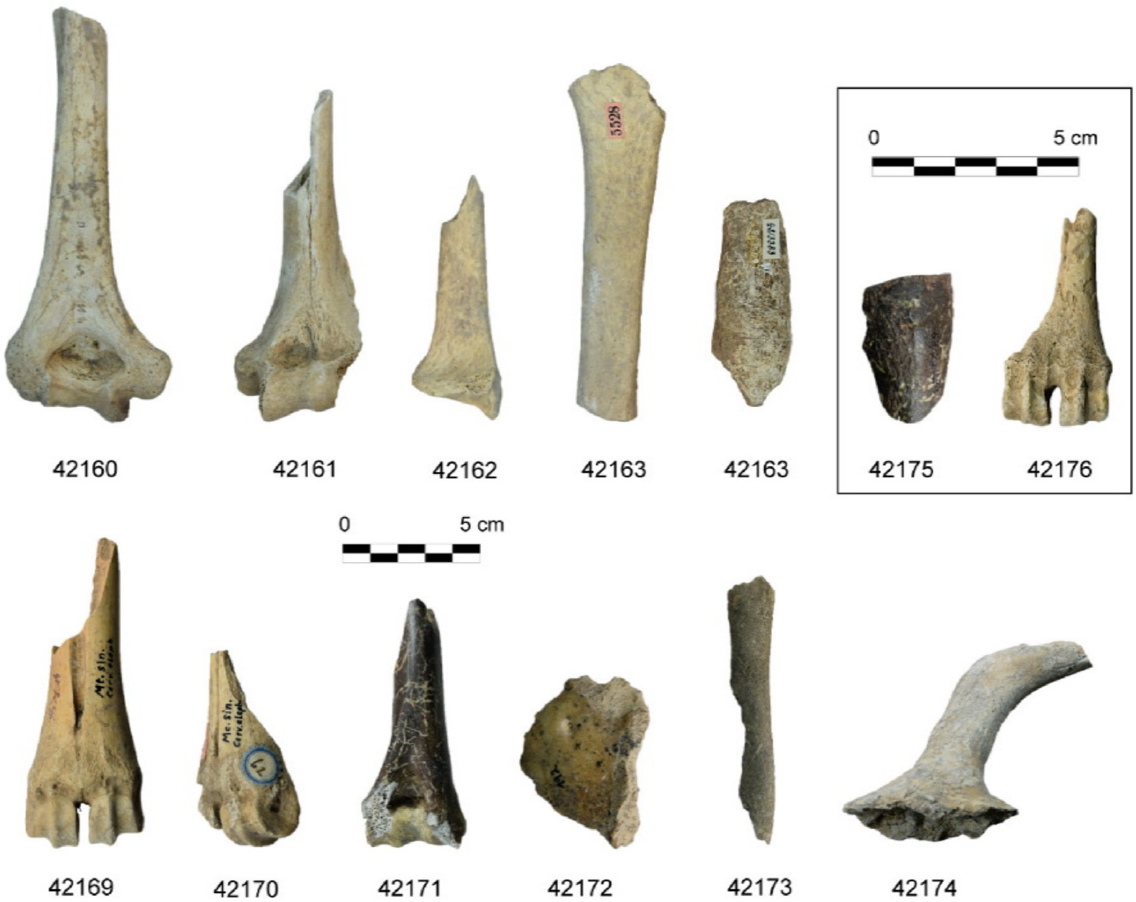

Fig. 4. The sampled faunal and human remains as well as osseous artifacts.

associated with any detailed intra-site provenience data, the earlier Upper Paleolithic of the Wildscheuer appears to represent human presence during the 'classic' Aurignacian, reflected stratigraphically by layer III. In this context and as also noted by previous studies, adhering sediment with red ochre stains (von Cohausen's 'terra rossa') – visible on some of our samples – appears to be a robust signifier of the Aurignacian-age finds (Pettitt et al. 1998: 442, Terberger 1993, von Cohausen 1874).

The earliest Aurignacian occupation in Germany began around 43,000 calBP (Bataille and Conard 2018, Bertacchi et al. 2021, Conard and Bolus 2008). Specifically, the initial settlement by people associated with this technology in the Ach and Lone valleys of the Swabian Jura ~250 km south-south-east of the Lahn Valley predates the Aurignacian occupation in our study region (Conard and Bolus 2008, Higham et al. 2012). Our finding and the previous studies concur in that the earliest occupations in the Lahn Valley occurred during the late Aurignacian some millennia after its initial expansion into Europe. The absence of some key Aurignacian artifacts such as the antler split-based points also contrasts with that of the southern Swabian Jura (Kitagawa and Conard 2020). The Lahn Valley sample is small, however, and the presence or absence of supposed indicator artifacts should be viewed with due caution. In addition, judging by site number and size, the Aurignacian occupation in the Ach and Lone valleys was considerably more substantive than in the Lahn Valley. Notably, the material culture, specifically of the osseous technology, does differ considerably between the two regions (Wolf 2015). The delayed arrival of modern humans to the more northern fringes of Central Germany may help explain this discrepancy.

In WW, dates from the ursid remains show that their occupations predate that of human activities at WS. Duly mindful of our limited sample size, this may be taken to suggest that occupations of cave bear did not chronologically overlap with those of humans. Although they remain ubiquitous in caves until their extinction, this is in line with some findings that the presence of cave bears decreased during the Aurignacian in some regions (e.g., Swabian Jura – see Kitagawa et al. 2018, Toniato et al. 2024). While the cause of this phenomenon remains open to debate, the human occupation in the early Upper Paleolithic evidently correlates with the decreased presence of bears. This ursid species went extinct some thousands of years later (Pacher and Stuart 2009, Stiller et al. 2010) and given the marked effect of human dispersal on megafauna in the Late Pleistocene (Bergman et al. 2023, Mondanaro et al. 2019, Svenning et al. 2024), it is interesting to note the temporal overlap of human encroachment and the regional disappearance of cave bears. Human impact on local megafauna in general and ursids in particular can be tested further by dating additional bear remains from WS to see if ursid decline coincides with increasing human presence.

There is also an ephemeral Gravettian component to WS, which is demonstrated by the dated antler piece. The remain represents a likely occupation event in the warmer phase of the year (spring-summer) due to the fact that the antler remained attached to the crania. According to Maier and Zimmerman (2017), this date temporally fits in the second half of the Gravettian during which we see a contraction of population in Central Europe that started around 29,000 calBP. The Gravettian is also represented in Hesse outside of the Lahn Valley such as Adlerquelle (Floss 1991) or Mainz-Linsenberg (Hahn 1969), but it is likely that the region was depopulated during the Last Glacial Maximum. Based on the lithics and earlier studies of WW, renewed human presence in the Lahn Valley can be associated with the Magdalenian. Relevant radiometric dates center on ~15,000 calBP (12,835 BP) (Street et al. 2012) and align well with the current model of Late Upper Paleolithic occupations in Central Germany (Maier 2015, Taller 2014). Magdalenian dates are not

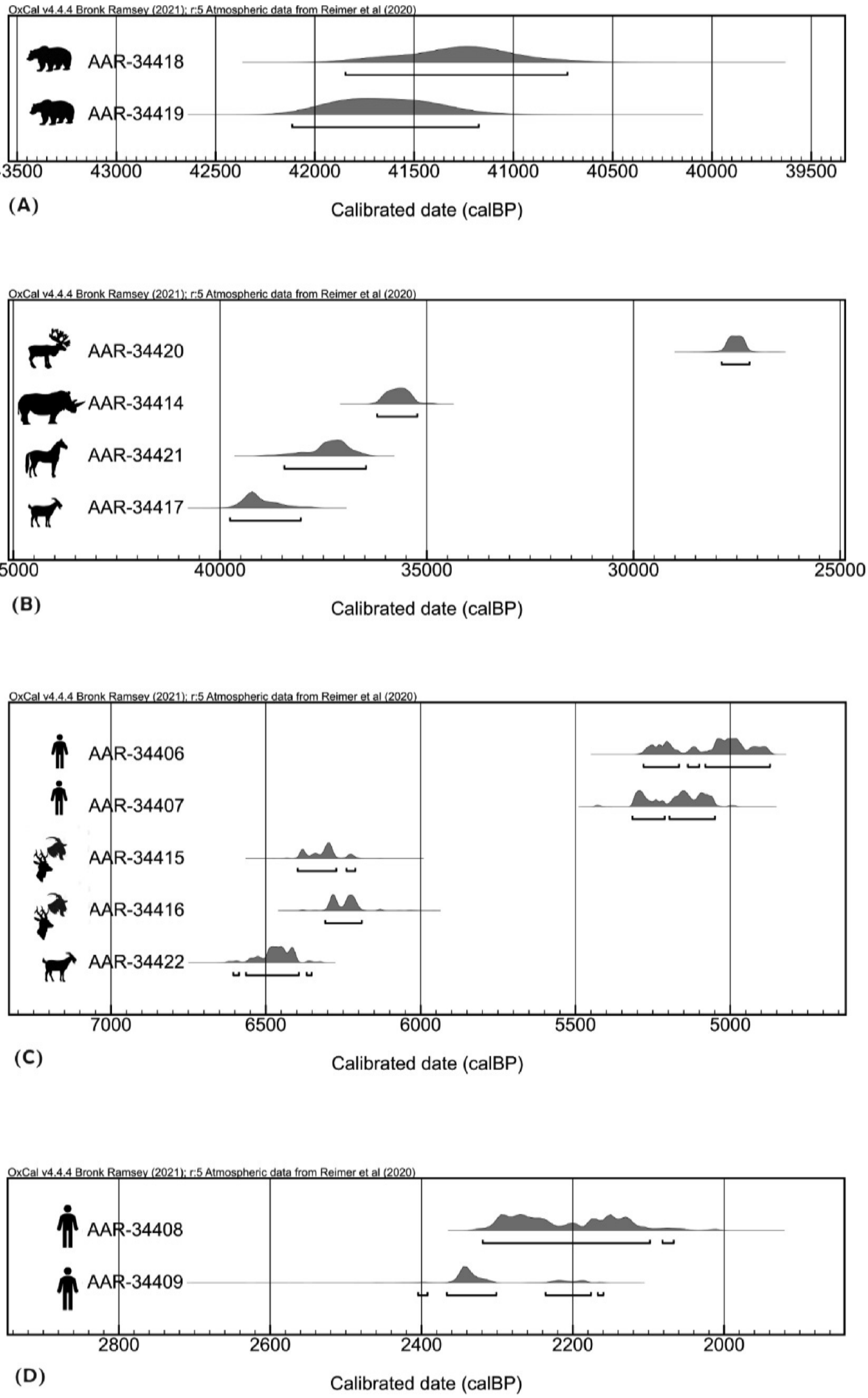

Fig. 5. Plots calibrated using IntCal20, OxCal v4.4.4 (Reimer et al. 2020). From top to bottom: Wildweiberlei (WW) dates as well as Wildscheuer (WS) Upper Paleolithic and Neolithic dates, and Wildhaus (WH) dates.

Table 4
Previously published dates from the Lahn Valley (Wildscheuer and Wildweiberlei). Data from Pettitt et al. 1998 (in Hedges et al. 1998) and Street 2011 (in Higham et al. 2011).

Site/Layer	Inventory #	Material	Species	OxA-number	^{14}C BP	±	Reference
Wildscheuer III	53/73–34 Sample 1	bone	reindeer	OxA-6807	30,050	550	Pettitt et al. (1998)
Wildscheuer III	53/73–34 Sample 2	ivory	mammoth	OxA-6920	34,100	1200	Pettitt et al. (1998)
Wildscheuer III	3: 53/73/23	bone	mammoth	OxA-7390	32,650	700	Pettitt et al. (1998)
Wildscheuer III	4: 53/73/29	antler	reindeer	OxA-7391	28,340	420	Pettitt et al. (1998)
Wildscheuer III	5: 1998 "18"	antler	reindeer	OxA-7392	31,050	600	Pettitt et al. (1998)
Wildscheuer III	7: 53/73/27	bone	reindeer	OxA-7393	33,350	750	Pettitt et al. (1998)
Wildscheuer III	8: 53/73/37	bone	?	OxA-7394	34,200	900	Pettitt et al. (1998)
Wildscheuer III	1: 53/73/29	ivory	mammoth	OxA-7498	20,480	360	Pettitt et al. (1998)
Wildscheuer III	6: 2063b "58"	bone	reindeer	OxA-7499	30,200	1100	Pettitt et al. (1998)
Wildweiberlei	57,1	antler	reindeer	OxA-18410	12,835	50	Street (2011)

represented in our sampling pool, however. Moreover, it is notable that the Lahn Valley caves do not contain evidence of human use by Final Paleolithic Federmessergruppen communities. Ephemeral evidence for their presence is known from the Lahn Valley and from Hesse in general, although the region does appear to have been comparatively peripheral at this time (e.g., Riede 2016).

Our new dates on the human remains demonstrate use of the caves in the Holocene, chiefly related to mortuary practices of the Neolithic, and concentrated in two discrete periods. Caves were habitually used as places of burial in the European Neolithic (Dowd 2008, Peterson 2019) and the Federal State of Hesse is no exception (e.g., Orschiedt et al. 2008, Riede and Sauer 2021). While not the focus of our investigation, we here stress the richness of the human osteological assemblage from the Lahn Valley. As with the older lithic and faunal remains, these human bones are poorly contextualized yet well-preserved offering the opportunity to apply a wide range of archaeometric and biomolecular methods to better understand their biological affiliations and origin.

Moving beyond merely positioning the human use of the Lahn Valley caves in time, our new analyses shed light on a new aspect of megafauna-human interactions. Based on the morphological and ZooMS identification, we have identified the use of rhinoceros rib to fashion osseous artifacts. While most zooarchaeologists consider the raw material of smoothers and smoother-like artifacts to derive from megafauna, the abundance of mammoth often outweighs that of wooly rhinoceros at some Upper Paleolithic sites in Central and Eastern Europe (Demay et al. 2021, Münzel et al. 2016, Svoboda et al. 2005). Mammoths are also found in large numbers in some assemblages, suggesting that their exploitation was more frequent and varied than rhinoceros, that is, they yielded food as well as raw material for osseous technology. While the current sample size remains limited, we assert on the basis of the novel results presented here that humans potentially exploited wooly rhinoceros alongside mammoth, the latter being directly evidenced in the Lahn Valley through the presence of ivory artifacts and teeth fragments (Terberger 1993, Turner et al. 2000, Wolf 2015). This will need further testing in the future with, for instance, the systematic study of zooarchaeological remains and megafauna-derived osseous artifacts.

The decisions to transport animal remains to sites are often predicated on multiple factors including the size of the animals or the distance to the site. For megafauna specifically (Lupo et al. 2016), this selection is often discussed in terms of returns for meat but may also be applied for osseous raw materials. The new evidence of occasional wooly rhinoceros exploitation for such raw material underlines the breadth of animal species targeted by these foragers, and the complexity of decisions involved. The evident breadth of megafauna targeted by humans also has implications for understanding anthropogenic impacts on ecosystems (Lemoine et al., 2023), given that megafauna played a keystone role in the functioning of Pleistocene ecological dynamics (Bakker et al. 2016, Malhi et al. 2016, Tóth et al. 2019).

6. Conclusion

We have here presented several new high-precision radiometric dates for the prehistoric human occupation of Lahn Valley caves, a well-known even if now regrettably destroyed cluster of sites located in the German Federal State of Hesse in Central Europe. Following an earlier presence of Neanderthals, the initial appearance of anatomically modern humans in these caves followed some millennia after the settlements of the early Aurignacian groups further to the south. The late Aurignacian material in Wildscheuer represents one such occupation pulse in Central Europe. The new dates presented here, together with those already available, suggest that the intensity of human use of these caves declined after the Aurignacian, possibly due to declining population densities in Central Europe in the runup to the Last Glacial Maximum. The Lahn Valley appears to have been abandoned during this very cold period and was subsequently resettled during the Magdalenian. For this period, relatively dense occupation is known from the Rhine area merely ~40 km to the west (cf. Terberger 1993, Street et al. 2012). That said, Magdalenian locales are otherwise rare in the Federal State of Hesse (but see Terberger et al. 2013); the area north and east of the Lahn Valley may have largely been devoid of people at this time. Moreover, the radiometric dating of the Lahn Valley finds also constrains the younger end of Paleolithic presence in the area. Final Paleolithic finds do occur in the Lahn Valley itself and in the wider region, but they are scarce suggesting an ephemeral use of this region.

Regarding the post-Pleistocene use of the caves, the general context of the human remains is currently not well defined and future bioarchaeological studies may reveal more about the depositional details and history of these human remains in the context of this catchment and the region at large. Questions remain about how we can explain the later occupations and land-use in the region. The Lahn Valley sites enable a direct comparison to others on an inter-regional level such as the neighboring core area of the Swabian Jura of southern Germany on the one hand and sites in the Rhineland on the other. Future studies in Central Germany deploying both traditional and emerging archaeological methods will shed more light on past human settlement dynamics in the region at large and their interactions with megafaunal animals.

CRediT authorship contribution statement

Keiko Kitagawa: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Daniel Burger-Völlmecke:** Writing – review & editing, Writing – original draft, Visualization, Data curation. **Sam Brown:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation. **Jesper Olsen:** Resources, Methodology, Formal analysis. **Felix Riede:** Writing – review & editing, Writing – original draft, Methodology, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2024.104951.

Data availability

Full ZooMS Data are available at https://doi.org/10.5281/zenodo.10839894. Other data will be made available on request.

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