



Technofunctional Analysis Reveals the Role of Carinated Artifacts and End-Scrapers in the Aurignacian of Vogelherd Cave

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Accepted: 12 July 2025
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Abstract

Cores and tools are essential for understanding the lithic assemblages of the Upper Paleolithic. However, carinated pieces, which are of central interest in the Aurignacian, are mostly defined by typological criteria. How researchers interpret these criteria varies greatly and has significant influence on the interpretation of sites and their functions. In the case of carinated artifacts and non-carinated end-scrapers, there is no unambiguous definition. Consequently, we are not using an *a priori* typological definition for grouping the artifacts. This article answers the question of whether a distinction between the two can be made linked to the morphology of the artifacts using a combination of functional analysis, refits, and morphological analysis. To pursue this question, we examine the Aurignacian assemblages of Vogelherd in the Swabian Jura of southwestern Germany. The two Aurignacian horizons IV and V are rich both in non-carinated end-scrapers ($n=807$) and carinated artifacts ($n=163$) providing a perfect case study for clarifying this enduring debate. We first sorted the assemblages into minimal raw material units using the physical properties of the raw materials and then identified several refitting sequences, of which sixteen are presented here. These refits permit a range of new observations combining morphological and microscopic analyses to facilitate a robust technofunctional interpretation. Based on these results, we view carinated artifacts as cores, which provide insight into the production of bladelets, bladelet tools, and their life histories. In contrast, we view end-scrapers as tools that highlight the specific tasks carried out on site. Our results show that traceological analyses can be used to overcome the weaknesses and ambiguity of typological approaches. This research illuminates the actions and behaviors of Paleolithic agents, thereby increasing the relevance of pre-historic artifact assemblages. At the same time, these results bring innovative technologies characterizing the Aurignacian into clearer focus and contribute to a better understanding of the potential differences in how expanding populations of modern humans in the early Upper Paleolithic employed technology relative to the Neanderthals of the late Middle Paleolithic.

Extended author information available on the last page of the article

Keywords Use-wear · Refitting · Hafting · Aurignacian · Carinated technology · End-scraper

Introduction

The role and definition of carinated pieces and end-scrapers as cores or tools have been the subject of research for a long time (e.g. Almeida, 2001; Bodu et al., 2013; Chiotti & Cretin, 2011; Dinnis, 2008; Hahn, 1969, 1988, 1991; Hays & Lucas, 2000; Le Brun-Ricalens, 1993, 2013; le Brun-Ricalens et al., 2005; le Brun-Ricalens & Brou, 2003; Movius & Brooks, 1971; Olszewski, 2007; Pesesse & Michel, 2006; Piette & Porterie, 1894; Schulte im Walde, 1987; Sonnevile-Bordes & Perrot, 1953). Summaries on the history of research on this topic (le Brun-Ricalens et al., 2005) and on the traditional typological and the more current technological definition (Le Brun-Ricalens, 2013; le Brun-Ricalens & Brou, 2003; le Brun-Ricalens et al., 2005) provide a good overview on carinated pieces and how they differ from end-scrapers. In these summaries, it is often stated that artifacts can have a dual function, as core and/or tool. Condensing the definitions of the aforementioned sources, the commonly used typological definition of these artifacts (e.g. Demars & Laurent, 1989) refers to the thickness of the blank or nodule used. Carinated pieces are, therefore, characterized by a thick blank or a thick raw material nodule, with end-scrapers being thinner. However, these definitions leave a lot of room for interpretation. What thick means is not defined most of the time, which leads to problems when assemblages are compared, especially when typology and the presence of carinated artifacts are used to argue that the Protoaurignacian and Aurignacian are two different technological traditions (Bon, 2002; Teyssandier, 2007; Teyssandier et al., 2010) or that they are two distinct and successive phases of the Aurignacian (Banks et al., 2013), while others argue against this (Bataille et al., 2018; Tafelmaier, 2017). The name-giving characteristic of carinated artifacts is the keel. This carination can be further developed using lateral notches. Here, too, it often remains unclear how strongly an artifact must be carinated to be considered as such and how to measure this. Definitions like the carinated index of Laplace were also used to differentiate between a carinated piece and a flat end-scraper (Laplace, 1966). Here, the ratio of width to thickness of the artifacts is used for the definition of the index. However, Laplace's work focused more on typological considerations and not on the functional indications for the definition of cores or tools.

Technological definitions highlight the production of bladelets from the front face of these carinated artifacts. This definition, with modifications for each type (carinated end-scraper, carinated nosed end-scraper, and carinated burins with different subtypes), is also found in this or a slightly modified form by other researchers that worked in SW Germany (e.g. Hahn, 1988, 1991). The definition of the carinated pieces as cores is complemented by some authors with further technological descriptions, e.g., by performing maintenance operations (Aleo et al., 2021; Chiotti, 2000; Falcucci & Peresani, 2018; Hahn, 1988; le Brun-Ricalens & Brou, 2003; le Brun-Ricalens et al., 2005; Parow-Souchon & Belfer-Cohen, 2024). These are also directly supported by refits in some cases.

Much more important, however, is the fact that up until now, no evidence has been provided by means of traceological analysis to confirm these definitions. Some of the existing analyses of carinated pieces and end-scrapers from the Aurignacian showed good results (Hahn et al., 1988; Hays & Lucas, 2000; Schulte im Walde, 1987); however, they often used typological or technological definitions. Often, no information is provided on how the artifacts were defined as carinated or not carinated, and the definitions are not always sufficiently discussed. The paper on these end-scrapers and carinated end-scrapers from Fumane Cave should be highlighted for the detailed description of these artifacts (Aleo et al., 2021). Due to the similarity of the process of creating a half-round working edge of a tool and a half-round reduction surface of a bladelet core, different scenarios can be created if we use a technological and morphological definition to separate them (Fig. 1):

1. Clear separation between carinated bladelet cores and tools.
2. Sharp separation of carinated bladelet cores and tools.
3. Overlap between carinated bladelet cores and tools, which results in the inability to separate them by means of the chosen definition.

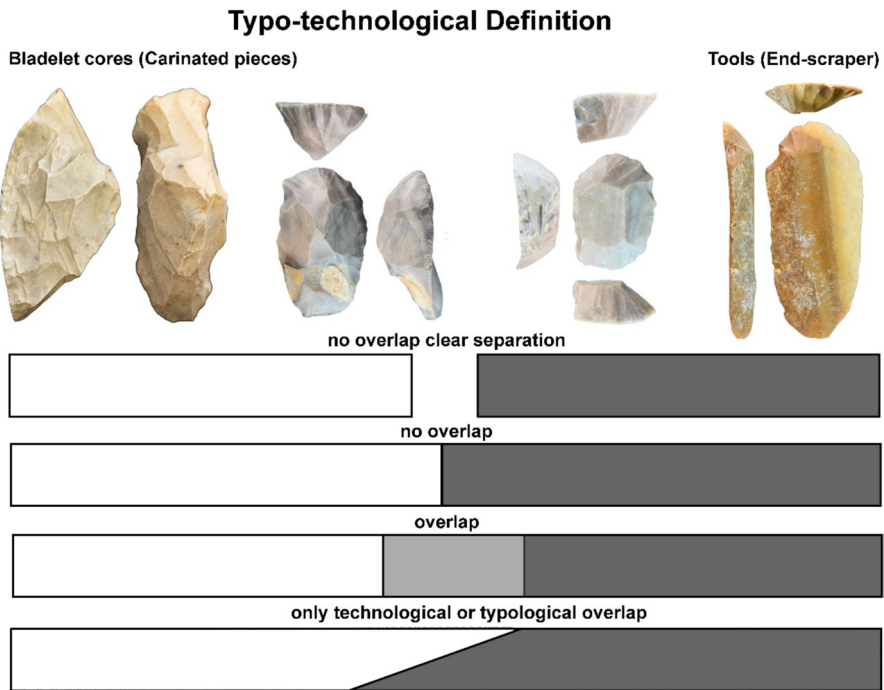


Fig. 1 Different Scenarios for the technotypological definition of bladelet cores and end-scrapers (carinated pieces and end-scrapers from left to right: AH:IVo ID:461; AH:IV ID:564; AH:IV Pa ID:569 (4951); AH:IVu ID:608 (3534); photos: B. Schürch)

4. Typological and technological definitions separate the two groups unequally, so that there must be either a weighing against each other or tools and bladelet cores overlap again.

Bladelets can be the product of intentional production of a target blank, but they can also be a by-product of the shaping of the scraper cap, or they can even occur during core configuration (e.g., dorsal reduction). Furthermore, bladelet cores could be used as tools in a second phase after the reduction. All the abovementioned difficulties result in problems of finding a suitable separation between cores and tools in the case of carinated pieces. These problems allow very different interpretations of the Aurignacian assemblages, depending on the analyst and their definition of what a carinated piece is.

Kelly approached the same problem for hand-axes and was able to demonstrate from this example how different the conclusions can be that we draw on human behavior depending on the interpretation we draw from lithic assemblages (Kelly, 1988; Olszewski, 2007). Kelly states:

“Archaeologists need to develop the methods which will allow the detection and interpretation of patterns indicative of the use of a particular class of tools in a particular role” (Kelly, 1988, 732).

Thus, applying the logic of Kelly (Kelly, 1988) which was also used by Olszewski (2007), different interpretations arise for lithic assemblages, depending on how carinated pieces (cores) and end-scrapers (tools) are defined. These are related to the proportions of these artifacts in the assemblages, technological strategies, and their use. We try to achieve this by combining morphological and technological data together with results from our traceological investigations. The information from the traceological data is of central importance. We contextualize the results with refits and the sorting of minimal raw material units. Minimal raw material units are defined as all artifacts that belong to a unit most likely originating from one nodule (Adler et al., 2003; Conard et al., 1995; Hahn, 1988). The use-wear study was conducted without prior classification of the artifacts into end-scraper or carinated piece categories. The artifacts are classified into the category end-scraper if they were used as tools, or into the category carinated end-scraper if they were not used as tools according to our traceological analysis. This allows us to see possible trends that emerge from the use-wear study, detached from the typological or technological definition without being biased. By further contextualizing the lithic assemblage in a separate article (Schürch et al., in prep.) focusing on core reduction strategies at Vogelherd, the results are embedded into the *chaîne opératoire* of the sites Aurignacian occupation and assemblage.

Materials and Methods

Vogelherd was excavated in 1931 almost completely (Riek, 1932, 1933, 1934). The Aurignacian of Vogelherd (AH IV and V) is best known for its figurative art, musical instruments, personal ornaments, split-based points, and a variety of other artifacts (Boger et al., 2014; Bolus & Conard, 2006; Conard et al., 2015a, b, 2003;

Conard, 2016; Conard & Bolus, 2003; Conard & Seidel, 2008; Conard et al., 2016; Conard et al., 2013; Dutkiewicz, 2021; Hahn, 1977, 1986; Kitagawa & Conard, 2020; Niven, 2006; Schürch et al., 2023, 2022, 2021; Wolf, 2015). Previous studies demonstrate the important role of the site in Central Europe, especially highlighting the abundance of art objects, personal ornaments, and the large number of organic and lithic artifacts from the site's Aurignacian.

The Aurignacian lithic assemblage of Vogelherd (Chang, 2015; Conard & Bolus, 2006; Hahn, 1969, 1977; Kind, 1977; Riek, 1932, 1933, 1934; Sonneviller-Bordes, 1966, 1971) originates from layers IV and V dating to between 41,000 and 35,000 cal BP (Conard & Bolus, 2003, 2008; Conard et al., 2003). For this study, both layers were analyzed together as lithic refits ($n=141$) show that only a rough subdivision within the Aurignacian is possible (Schürch & Conard, in prep.). The refits carried out allow more accurate conclusions to be drawn for a subset of the artifacts analyzed in this study (Fig. 2).

The assemblage of layer IV and V ($n=5710$) was analyzed using attribute analysis (e.g., Hahn, 1991). Besides the artifacts from layers IV and V, artifacts from the backdirt were also included in the study. These could be contextualized by refits or by classification through minimal raw material units, or in a few cases by typological attribution (for more detailed explanation see supplementary).

In total, 128 end-scrapers/carinated pieces were selected for traceological analysis, with the aim of getting a sample of different morphologies of scraper heads of relatively well-preserved artifacts. From AH IV, IV/V, and V, 970 end-scrapers or carinated pieces were present. Then, 62 of the 128 artifacts originate from layer V, three from layer IV/V, 39 from layer IV, 23 from Conard's backdirt excavation (geological layer HL/KS of the backdirt), and one from the Collection Seeberger (collection from the backdirt). Then, 13 bladelets were refitted to ten end-scrapers/carinated pieces and were, therefore, analyzed as well for use-wear traces. The bladelets come from layer IV ($n=1$), layer V ($n=1$), Conard's excavation ($n=10$), and the Seeberger collection ($n=1$). The origin of the artifacts is indicated by the archaeological horizon/AH (1931 excavation) the geological horizon/GH (Conard's excavation) or collection seeberger (backdirt).

The terms (carinated or not-carinated) used in this paper to describe the artifacts are applied after the traceological analysis. This use of the terms therefore might not always align with the typological definition. The term carinated (carinated burin, carinated end-scraper, and carinated nosed end-scraper) is used in the following to address the artifacts that were not used as tools; therefore, they are interpreted as cores for bladelet production. The term end-scraper, without the addition of the word carinated, is applied to pieces that were used; therefore, they are interpreted as tools. The terms are therefore used independently of technological or typological definitions. If they were completely resharpened, or the interpretation was unclear, they were not sorted into these categories in our initial analysis.

The traceological analysis was carried out at the TraceoLab of the University of Liège using a Zeiss stereomicroscope Stemi 2000C with an external light source and magnifications up to $\times 56$ and a Zeiss Vario metallurgical microscope with incident light and bright-field illumination using magnifications up to 500x. Additional analysis was conducted at the Material Culture Laboratory at the University of Tübingen



Fig. 2 Overview of the Vogelherd assemblage and the variety of tested artifacts; description of the artifacts was done after the traceological analysis. (1–2) Double end-scrapers; (3,5,7) end-scrapers; (4) end-scraper/pointed blade; (6) carinated end-scraper/truncated-faceted core; (8) busked burin; (9) carinated burin/busked burin; (10) carinated nosed end-scraper; and (11) double carinated piece (all Jurassic chert or impregnated Jurassic chert; photos: B. Schürch)

using an Olympus SZX7 microscope with magnification ranging from $8\times$ to $56\times$ (objective: Olympus DFPLAPO1X-4) equipped with a LED ring light source and an Olympus BX53M metallographic microscope using magnifications up to $500\times$ (objective: Olympus LMPlanFL N). The observations under the stereomicroscope (lower magnification) were helpful for evaluating the preservation of the artifacts and for identifying the relative hardness of the worked material (Odell, 1977; Odell

& Odell-Vereecken, 1980; Semenov, 1964; Tringham et al., 1974). In addition, the low power approach was used to evaluate resharpening processes. The higher magnifications were used for a more detailed analysis of the polishes, rounding, and striations revealing the worked material (Keeley, 1980; Keeley & Newcomer, 1977) and for a subset ($n=31$) of the 128 pieces, also the hafting arrangement was recorded (Rots, 2003, 2005, 2010).

The results from the traceological analysis were combined with morphological measurements of the artifacts and the scraper heads (Lemorini et al., 2016). The morphology of the artifact (length, width, thickness, and weight as an indicator of the volume) could show which prerequisites distinguish cores and tools from each other. One possible assumption we had is that hafting and handling place certain requirements on the dimension of the artifacts (Kuhn & Shimelmitz, 2023; Rots, 2002, 2003, 2005, 2010). Similarly, one could assume that the production of bladelets requires a minimum size or volume. The scraper head was measured thoroughly (the thickness, width, length, radius, and angles at the edges of the scraper head, Fig. 3). These could indicate prerequisites of the dimensions or angle of the working edge of tools of production. In addition, the number of visible bladelet negatives on the scraper head and the length and width of the biggest bladelet negative were recorded as well to document the size and quantity of the produced bladelets from the largest visible reduction or resharpening cycle.

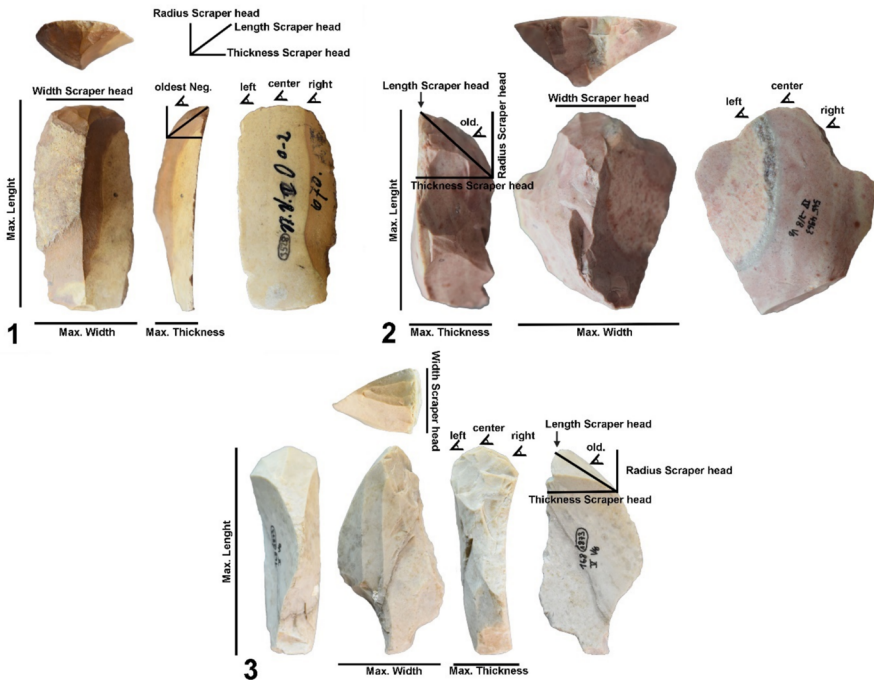


Fig. 3 Overview of the measurements: (1) end-scraper and carinated end-scrapers, (2) nosed end-scrapers and carinated nosed end-scrapers, and (3) carinated burins and busked burins (illustration: B. Schürch)

For our analyses, we used the extensive comparative collection of the TraceoLab of the University of Liège (Rots, 2021), which covers the use of the artifacts as well as the hafting of the end-scrapers (Rots, 2010). The comparative collection is complemented by a separate comparative collection created for the study ($n=29$) with all pieces used handheld. The collection was created using Jurassic chert, which represents the raw material of all but one artifact analyzed in this study. The other raw material present for one artifact is Tertiary chert (Schürch et al., 2022, 2025). This was necessary to understand the great variability of Jurassic chert, from very fine to coarse grained, which is not present in the TraceoLab reference collection, as this was made from mostly fine-grained flint from the Mons Basin (Rots, 2010). In addition to the materials that were worked in the TraceoLab reference collection (dry and fresh hide, wood and antler), soaked and dry ivory as well as plant matter (reed) were also included.

The state of preservation of the archaeological artifacts was quite varied. It spans from artifacts with no alteration to strong alterations. This was considered for the analysis, and artifacts with strong alterations were mostly excluded from the analysis and are not listed in the tables, nor were these considered for the analysis. Only seven artifacts with very strong alterations were included if they belonged to a refit group or minimal raw material unit. The varied state of preservation is best explained by differences in pedological processes inside of the cave and the forecourt of the cave.

The artifacts from the 1931 excavation had to be thoroughly cleaned. Often, they were covered with grease, probably from several previous analyses that could not be removed with ethanol or acetone alone. We used Acidic acid (3% solution) and sodium hydroxide (NaOH, 3% solution) to clean the surfaces as well as the ultrasonic bath. The artifacts from Conard's excavation of the backdirt did not need that procedure; here, the artifacts were only cleaned with ethanol or acetone and cotton pads.

All of the abovementioned information was entered into a MS-access database, including detailed information on polish, edge rounding, scarring patterns, striation, edge morphology, alterations, and resharpening. If the artifacts had two scraper heads, both of the ends were recorded in the same way. The information resulting from our traceological analysis (used, not used, completely resharpened, and unclear) is used for the analysis of the morphological data. We used independent samples *T*-test to compare the measurements of the used and not used artifacts. Then, we plotted these using PCA and separated them using LDA. The figures that show the whole artifacts were chosen to highlight the most prominent traces; this does not imply that traces were absent in the other areas. These are either shown in detail with micrographs or the zones with the prominent traces are marked in color (blue = wear traces on the scraper end, red = traces connected with hafting, and yellow = resharpened zones). To identify the threshold for the singular values, we used the means (see results of independent samples *T*-test) and medians (see results of boxplots). We also used ROC (receiver operating characteristic) curve analysis to identify the best values for separating the dataset and finding thresholds.

Table 1 Alteration of the analyzed sample

Alterations	<i>n</i>	%
No	3	2.3%
Low	43	33.6%
Medium alterations	52	40.6%
Strong alterations	23	18.0%
Very strong alterations	7	5.5%
Total	128	100%

Table 2 Use of the analyzed artifacts. If artifacts have two modified ends, they are listed separately

Material responsible	<i>N</i>	%
Hide	73	46.5%
Hide and secondary use on wood or bone	7	4.5%
Wood	2	1.3%
Not determined/unclear	13	8.3%
No use related traces	56	35.7%
Completely resharpened	6	3.8%
Total	157	100%

Results

Preservation and Evidence of Use

From the 128 artifacts, 96 were complete. Then, 32 artifacts were broken, which were not preserved in their original length. The 128 archaeological artifacts had a combined number of 157 modified ends. Of the 157 modified ends, 82 ends displayed traces of use, 56 did not display any traces of use, 13 of them were ambiguous or unclear, and six were completely resharpened and without any traces left on the possible working edge. Artifacts with two ends were, in twelve cases, pieces with two core ends; in eleven cases, pieces with two tool ends; and in three cases, a tool end (end-scraper) was combined with a core end (carinated or busked burin). Four pieces had one core or tool end and one not determined/unclear end.

Besides traces of use, we could detect clear hammer marks on 46 of the artifacts around the possible working or reduction edge. Alterations varied between very strong and no alterations (Table 1). The traces on artifacts with very strong alterations were not interpreted and can be found under the category not determined/unclear in Table 2. The artifacts with strong or very strong alterations were most clearly influenced on the edges and the most exposed/protruding parts of the artifacts (Figs. 4 and 6). The traces left by the alteration are regular edge rounding and an alteration polish. This polish is present not only on the edges but also on the most exposed parts of the artifacts. Influence of heat or fire is generally present in the Aurignacian assemblage of Vogelherd with 2.42% of the 5710 artifacts. However, no artifacts with these alterations were included in the sample.

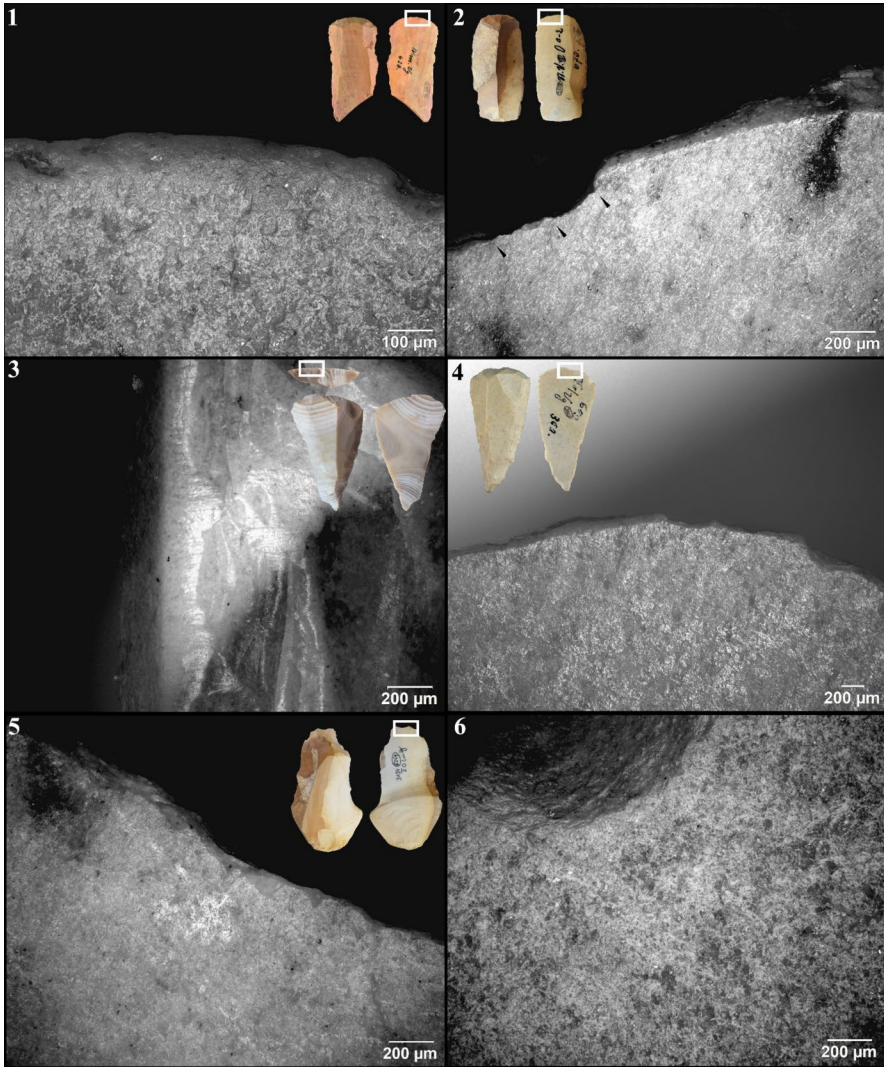


Fig. 4 Overview of wear traces and alteration: (1) hide-working traces: developed rounding and rough polish on scraper head, ventral (200x; AH:IV; ID: 626 (5459)); (2) hide-working traces: developed rounding and rough polish cut by resharpening (arrows) on scraper head, ventral (100x; AH:V 4 m; ID: 394 (3680)); (3) hide-working traces: developed rounding and polish with striations on scraper head and on the ridges of the retouch of the scraper head, between ventral and dorsal (100x; GH:HL/KS; SQ:41/68; ID:79.1); (4) hide-working traces: developed rounding and polish on the edge of the scraper head and alterations on the inside, ventral (50x; AH:Vo; ID:300 (360)); (5) Hammer traces, ventral (50x; AH:V 0 2 m; ID:3134 (5215)); (6) alterations: very strong alterations combined with striations, ventral (100x; AH:V; ID:678 (94)) (micrographs: B. Schürch; all with Olympus BX53M)

The material responsible for the use traces was mostly hide (Table 2). Traces of hide-working were in few cases mixed with traces of secondary use on wood or bone, mostly represented by edge scarring. Wood was only detected in two cases.

The best indicator for hide-working was edge rounding (Fig. 4, 1-4). The rounding was paired with a dull polish (Fig. 4, 1), which was mostly limited to the area also affected by rounding (Keeley, 1980; Rots, 2005). Striations that corresponded with the rounding and polish were documented in 15 cases (Fig. 4, 3). It was also worth looking for traces on the ridges of the retouch of the scraper heads (Taipale & Rots, 2020), mostly with low magnification. Here, rounding, polish, and sometimes striations are present on the ridges of the retouch for 58 artifacts (Fig. 4, 3). This can be even the case when artifacts were resharpened (46 of 58). The traces on the ridges of the scraper head also show that large parts of the scraper head were in contact with the worked material (hide) at an angle between the scraper head and the hide of around 90°. The traces on the dorsal ridges were present on some scrapers that were first used on hide, and afterwards, there was a use on wood or bone. There, the traces on the ventral face are overprinted by scarring of the edges and brighter polish that was more limited to the edges.

Resharpener was documented for 79 of the artifacts. The intensity of the resharpening ranges from resharpening of the entire working edge to a resharpening only present in limited areas of the scraper head (Fig. 4, 2). If the resharpening affected the whole working edge, the artifacts were sorted into category “completely resharpened” (Table 2). For the other artifacts with resharpening, at least parts of the use traces were preserved. In some cases of the artifacts analyzed for hafting, the resharpening and its extension can be indicative for hafting limit (see below).

Morphological Differences Between Used and Not Used Artifacts

To show differences between the analyzed artifacts, we used the results from our traceological analysis and grouped them into the two categories, used or not used as tools. If the results of the traceological analysis were unclear, or the artifacts were completely resharpened, we did not include them. With these two categories, we performed independent samples *T*-tests for the dimensions of the blanks (thickness, width, and length) and for the thickness, width, length, radius, and angles at the edges of the scraper head. The *P*-value of the *T*-test shows a significant difference between the used and the unused artifacts (Table 3) for blank size (width, thickness, and length), the dimensions of the scraper head (thickness, width, length, and radius), and the number of bladelet negatives and the size of the biggest bladelet negative (width and length). However, the edge angle does not seem to be significantly different between the used and unused artifacts.

Hafting Evidence of Combinations Tools (End-Scraper/Pointed Blade)

For a more detailed analysis of the hafting and hafting arrangement we selected combination tools that combine one scraper end with one pointed end ($n=23$: $V=16$; $IV/V=1$; and $HL/KS=6$). All the scraper ends that were not completely resharpened or damaged were used to work hide. On all the tested artifacts, we could find hafting traces that showed similar patterns (Figs. 5 and 6 and S1-7). They often showed hafting scars at the limit of the haft but often also intense

Table 3 Comparison of the means of morphological measurements of artifacts used or not used as tools (**n* for the length of the blank differs because broken artifacts were excluded in this category). Carinated burins are included here. Artifacts with the result “unclear” or “completely resharpened” from the use-wear analysis are not included here

Results for all analyzed artifacts	Group	<i>n</i>	Mean	Standard deviation	Standard deviation of mean	<i>P</i> -value
Blank						
Length* in mm	Used	66	55.09	18.06	2.22	0.007
	Not used	53	47.66	11.05	1.52	
Width in mm	Used	82	25.79	5.25	0.58	<0.001
	Not used	56	32.15	8.52	1.14	
Thickness in mm	Used	82	8.89	2.08	0.23	<0.001
	Not used	56	19.01	7.12	0.95	
Scraper head						
Width in mm	Used	82	20.52	6.09	0.67	0.003
	Not used	56	24.57	8.60	1.15	
Thickness in mm	Used	82	7.73	1.95	0.22	<0.001
	Not used	56	18.13	5.76	0.77	
Radius in mm	Used	82	6.05	3.39	0.37	<0.001
	Not used	56	14.85	7.72	1.03	
Length in mm	Used	82	10.23	3.42	0.38	<0.001
	Not used	56	23.04	7.04	0.94	
Angle oldest negative	Used	82	50.94	9.83	1.09	0.868
	Not used	56	51.23	10.52	1.41	
Angle at the left	Used	82	73.06	9.57	1.06	0.530
	Not used	56	74.14	10.15	1.36	
Angle at the center	Used	82	76.00	12.30	1.36	0.642
	Not used	56	77.04	13.56	1.81	
Angle at the right	Used	82	74.15	13.11	1.45	0.449
	Not used	56	75.80	11.77	1.57	
Number of bladelet negatives	Used	82	3.33	2.31	0.26	<0.001
	Not used	56	5.64	2.91	0.39	
Length biggest bladelet negative in mm	Used	82	10.18	3.51	0.39	<0.001
	Not used	56	22.41	7.30	0.98	
Width biggest bladelet negative in mm	Used	82	4.51	1.79	0.20	<0.001
	Not used	56	7.37	2.81	0.38	

scarring and rounding on the pointed end (Fig. 5, 1-3). The scarring on the pointed end seems to intensify with a decrease in length of the artifacts. The hafting scars were often paired with hafting bright spots (Figs. 5, 5-6 and 6). On the ventral face of the pointed end, we found bone/antler haft polish combined with rounding (Fig. 5, 3-4). We also found the same polish on the ridges of the negatives on the dorsal face (e.g., Fig. 6D). If the reconstructed hafting limit was

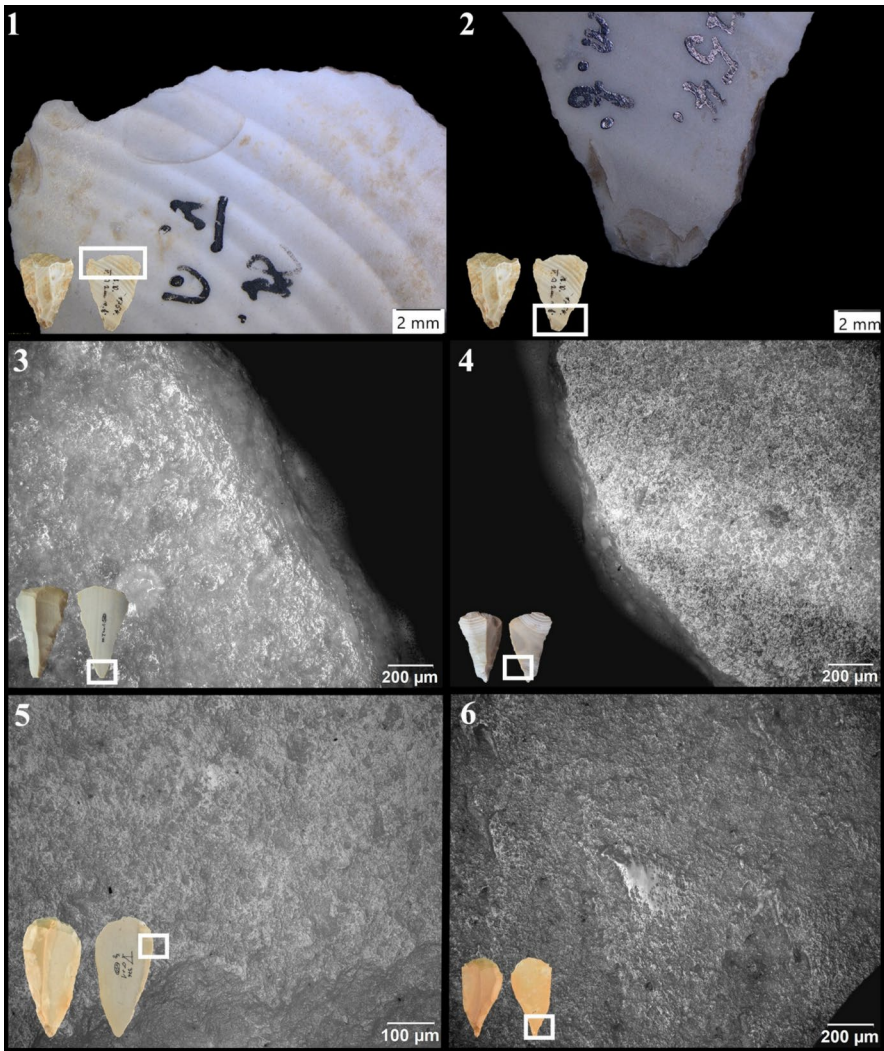


Fig. 5 Overview of wear traces and alteration: 1. Resharpener pattern: working edge protrusion on the left side associated with hafting scarring, distal ventral (8x, AH:Vo ID:1754 (116)); 2. Hafting traces: hafting scarring on pointed end, proximal ventral (8x, AH:Vo ID:1754 (116)); 3. Hafting polish: bone/antler haft polish and rounding at the pointed end, proximal ventral (100x, AH: V 4 m ID:394 (3680)); 4. Hafting polish: bone haft polish, proximal ventral (100x, GH:HL/KS SQ:41/68 ID:79.1); 5. Hafting striations: small striation and hafting bright spot next to hafting scar, near hafting limit ventral (200x, AH:Vo+1 ID:376 (450)); 6. Hafting bright spot: bright spot, proximal ventral (100x, GH:HL/KS SQ:68/64 ID:13.1) (micrographs: B. Schürch; 1–2. With Olympus SZX7; 3–6. with Olympus BX53M)

close to the working edge of the tool, we could also observe the presence of a protrusion at the side of the working edge. That this protrusion is linked to the hafting limit indicates that this protruding part could not be resharpener because it was inside the haft or at the hafting limit. The same pattern is also present

VH GH:HL/KS SQ:41/68 ID:79.1

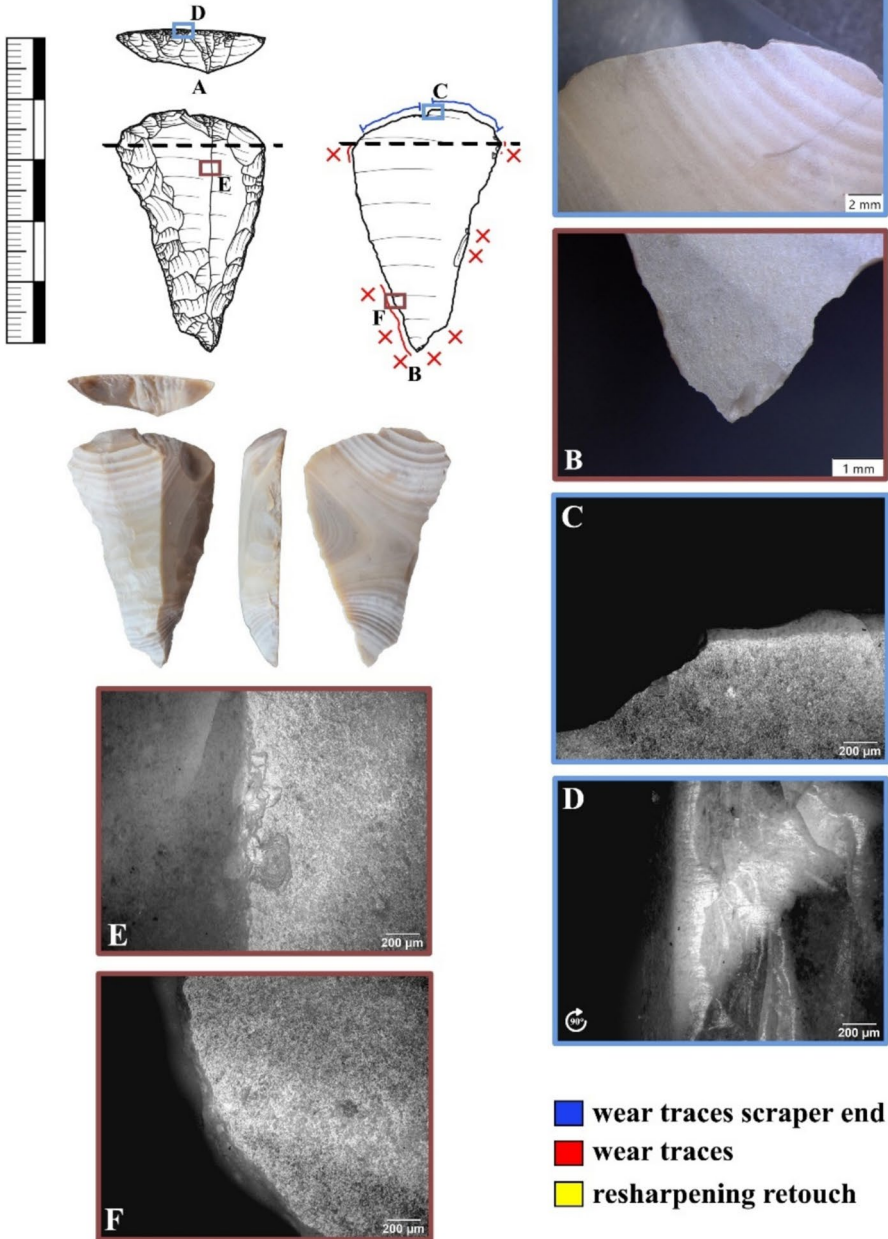


Fig. 6 Combination tool, end-scaper/pointed blade from minimal raw material unit JH1u (GH:HL/KS SQ:41/68 ID:79.1): (A) hide-working traces: working edge with small, damaged zone in the center (8x); (B) hafting scarring: proximal tip with hafting scarring (20,5x); (C) Hide-working traces: rounding and polish cut by damage (100x); (D) hide-working traces: developed rounding and polish with striations on scraper head and on the ridges of the retouch of the scraper head, between ventral and dorsal (100x); (E) Hafting scarring: scarring of ridge, dorsal (100x); (F) hafting polish: bone/antler haft polish, ventral (100x) (micrographs, photos and drawing: B. Schürch; A–B. With Olympus SZX7; C–F. with Olympus BX53M)

for two end-scrapers from the minimal raw material units (see below). For some artifacts the resharpener in the haft can lead to a change of the morphology (Gallagher, 1977; Jardon Giner & Sacchi, 1994) sometimes from a regular end-scraper to a more “nosed” characteristic of the end-scraper. The patterns observed on the combination tools (end-scraper/pointed blade) make it possible to reconstruct the hafting arrangement and the process of resharpener of the tools in the haft. The traces of either a bone or antler haft and the pointed end can be interpreted as indicators for a male hafting arrangement in a hollowed long bone or split bone (Rots, 2005, 2010) or hollowed (Rots, 2002; Taipale & Rots, 2020) or split (Allain et al., 1985) piece of antler. In a male hafting arrangement the tool is inserted into a hole, a concavity or a groove (Rots, 2005, 2010).

The intense scarring on the smaller combination tools can probably be explained by the necessity to wedge or lock these pieces in place into the haft due to their small size. Another possibility is that the intensive scarring was caused by repeated resharpener. Due to the presence of hide polish on the ridges of the retouch of the scraper head, a perpendicular use on the material worked is likely. It is therefore plausible that the artifacts slowly decreased in length/size during use resulting from resharpener (Frison, 1968; Gallagher, 1977). After a certain time, the artifact is no longer functional, because it can no longer be resharpener or can no longer be held in a stable position in the haft.

The end-scrapers from the raw material units tested for hafting (see below), that do not combine a scraper with a pointed end, show similar patterns to the combination tools. This may not show the full variability of hafting of the assemblage from Vogelherd, but it indicates that hafting of end-scrapers was common (Fig. 7).

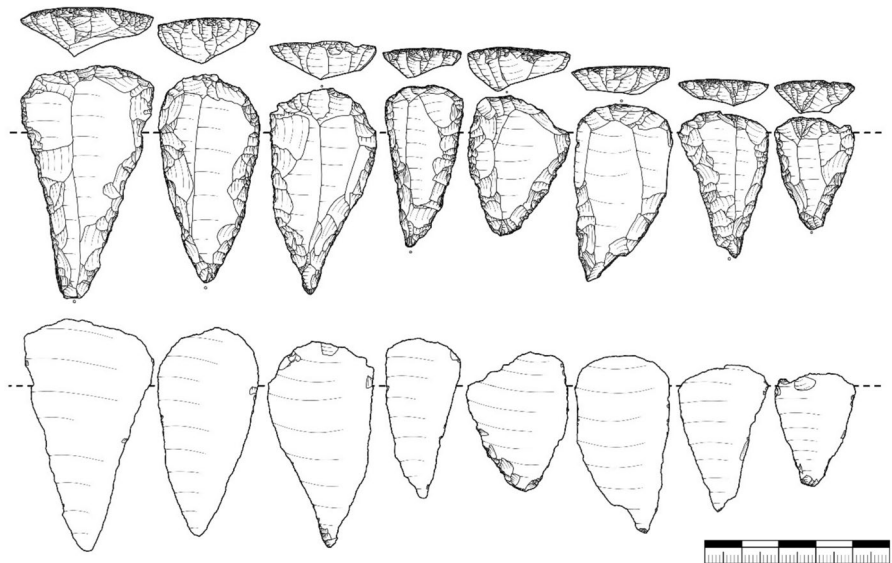


Fig. 7 Overview for size comparison of combination tools (end-scraper/pointed blade) and the reconstructed hafting limit (dashed line in the background)

Scrapers from Minimal Raw Material Units

To improve our understanding of the use of end-scrapers and carinated pieces, we chose to combine the data of our use-wear analysis with the data from refits and minimal raw material units. The refits can help us reconstruct the original length of the tools. The minimal raw material units presented here are to be understood as nodules and all corresponding tools, blades, flakes, and bladelets we could identify. This indicates what tools and blanks were produced on site and for what they were used. The artifacts from minimal raw material units ($n=6$) were further analyzed for hafting traces.

The most informative minimal raw material unit with end-scrapers and carinated pieces is unit JH1w. This unit contains 79 artifacts in total, two cores and 23 formal tools. Then, 18 artifacts from this unit could be refitted. Seven of the 23 tools are end-scrapers, truncated pieces, or carinated nosed end-scrapers (definition of the artifacts applied post-traceological analysis). One of them had to be excluded from the analysis because of very strong alterations. Four others were analyzed in detail, and traces of use were recovered from three of them. For the nosed end-scraper (AH: IV -7/8 ID:545 (4963)), no traces of use could be recovered (Fig. 8, 4); therefore, this piece was only used to produce bladelets. The three other end-scrapers all showed traces of use and hafting. For these three, we could reconstruct the original length of the blades. One of them (AH:IV m ID:1376 (3393)) had a negative of the cores' base left on the distal end; therefore, the configuration and resharpening of the end-scraper did not remove much of the distal part of the blade (Fig. 8, 3). Few traces of resharpening are present on this piece. A second end-scraper (AH:IV ID:626 (5459)) is part of refit 114 (Fig. 8, 1). From this refit, we could reconstruct the length of the blade, where only roughly 0.5 cm of the original length of the end-scraper was used for configuring the working edge. No traces of resharpening are present on this end-scraper. The third end-scraper (AH:backdirt ID:(10,327)), manufactured on a crested blade, is part of refit 118 (Fig. 8, 2). From this refit, we can also reconstruct the length of the crested blade; here, intense resharpening is present, and almost half of the original length of the artifact is gone, around 3 cm. Use traces are only present on the side of the scraper head due to repeated resharpening. All three end-scrapers that showed use traces also have traces of hafting. Hafting traces consist of hafting scars, hafting bright spots, and rounding of the dorsal ridges from contact with the haft. These traces are concentrated around the reconstructed hafting limit. Besides the direct information on the three tools and the one carinated core, we get more detailed information from the minimal raw material unit. It is likely for unit JH1w that the tools were produced on site since the preparation flakes, the core, and 18 artifacts from this unit were refitted together and are present in the assemblage. It is, therefore, also likely that the tools were used on site and one of them (ID:(10327)) was also resharpened several times (Fig. S8). This evidence suggests a long occupation of the site and highlights the variety of tasks conducted by the Aurignacian foragers at Vogelherd. The minimal raw material unit provides further insights into the use of this specific nodule. With the five end-scrapers and the one truncated piece, we could reconstruct hide-working activities. For four of them, we could reconstruct the use in a haft. Two of these end-scrapers are directly refitted

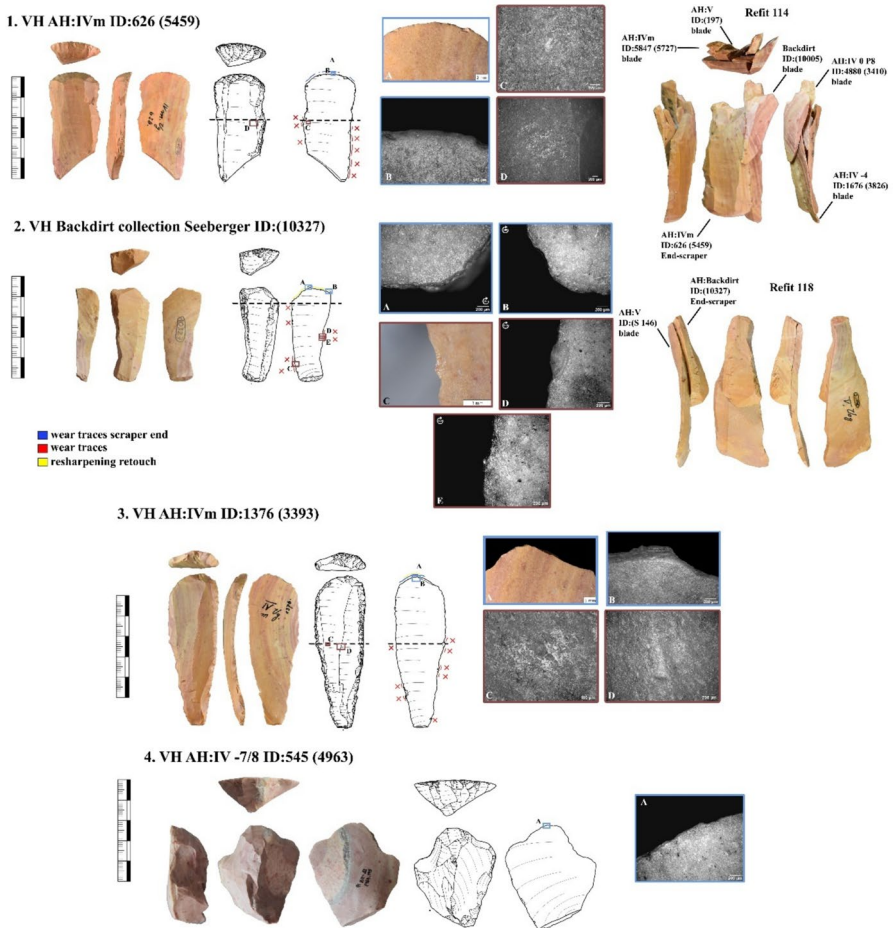


Fig. 8 End-scrapers and carinated nosed end-scraper of minimal raw material unit JH1w: (1) end-scraper (AH:IVm ID:626 (5459)) that is part of refit 114: (A) working edge of the scraper head the few scars are not patinated and therefore recent, ventral (8x); (B) Developed rounding and flat polish on scraper head, ventral (200x); (C) Hafting bright spot associated with scar, ventral (200x); and (D) Several hafting bright spots associated with rounded ridge, dorsal (50x). (2) End-scraper (AH:IVm ID:1376 (3393)): (A) working edge of the scraper head not the complete edge is retouched, ventral (8x); (B) developed rounding and polish on scraper head, ventral (100x); (C) hafting bright spot near rounded ridge, dorsal (200x); and (D) rounded ridge, dorsal (100x). (3) End-scraper (backdirt collection Seeberger ID:(10,327)): (A) weakly developed rounding and polish on scraper head, ventral (100x); (B) rounding and polish on the side of the scraper head cut by resharping, ventral (100x); (C) hafting bright spot below scarring, ventral (4x); (D) diffuse bright spot next to hafting scar, ventral (100x); and (E) hafting bright spot close to D (100x). (4) Carinated nosed end-scraper (AH:IV -7/8 ID:545 (4963)): (A) unmodified edge with light alterations, ventral (100x) (photos and drawing: B. Schürch; micrographs: Olympus SZX7; Olympus BX53M)

with unretouched blades. These were possibly used for cutting activities. The two burins point towards incising or shaving activities. Several retouched blades, bladelets, and flakes point towards the use of these blanks. The six splintered pieces point

towards splitting activities. For one of the splintered pieces, it is also visible that the piece had a scraper head before the splintering happened.

Another artifact included in the study is from minimal raw material unit JH1d. The end-scraper showed both traces of hide-working and hafting. The artifact is resharpened intensively, and traces of use are only preserved on a limited area. Hafting traces, several hafting bright spots, both on the dorsal and ventral side, and hafting scars are present. Then, 48 artifacts are part of this minimal unit, one core and 11 tools and 36 blanks. One end-scraper is part of this unit. The end-scraper (GH:HL/KS SQ:57/64 ID:57) is part of refit 98 (Fig. 9, 1). Four tools are part of this refit, the scraper, a pointed blade broken in two and a retouched blade. The proximal part of none of the tools involved in the refit is preserved, but the distal end is for the retouched blade. Therefore, we can reconstruct that the distal end was approximately 1.5 cm longer before the artifact was configured and resharpened. The end-scraper also showed traces of hafting like the end-scrappers from JH1w. The second end-scraper (AH:IV ID:2431) is part of refit 38 + 39 and was used for hide-working (Fig. 9, 2). In this refit nine pieces were refitted, all blades or blade fragments. From this refit we could recover one end-scraper, four retouched blades and four unretouched blades. The end-scrappers are part of a minimal raw material unit JH1d, that was reduced on site. This can be shown by several preparation flakes, the core and 25 artifacts from this unit that were refitted back together. The end-scraper, burins, retouched blades, pointed blades, truncated blades and retouched bladelets are part of the tool spectrum of this unit. For this unit it seems also likely that the tools and blades were used over a longer period and for various tasks just like the ones from unit JH1w.

Refits of Carinated Pieces and Bladelets

Another approach to understand the *chaîne opératoire* of the end-scrappers as well as the carinated pieces and to verify the results of our traceological analysis is to include refits of end-scraper/carinated pieces and bladelets removed from them (Figs. 10, 11, and S9-16). If the bladelets are used to resharpen the working edge, they may show traces of previous use around their platform (Venditti et al., 2022). However, if the end-scraper/carinated piece and the bladelets lack any traces on the striking surface, this could indicate that the pieces were part of reduction sequences of bladelets. If the bladelets themselves show traces of use that are not on the striking surface or indications of hafting, it is likely that these bladelets are target products as well.

A total of ten refits from the Vogelherd assemblage were analyzed. Some of them come from the minimal raw material units. Following the technofunctional analysis, six of them are interpreted as carinated end-scrappers (Figs. 10 and S9-13) that produced bladelets. Three are interpreted as tools that were resharpened (Figs. 11 and S14-15), and the interpretation of one piece is unclear due to alteration and damage on the piece (Fig. S16). For the interpretation of the cores, several attributes had to add up: missing use-wear traces at the scraper head, missing traces of previous use on retouched edges, missing hafting traces, and missing traces around the platform

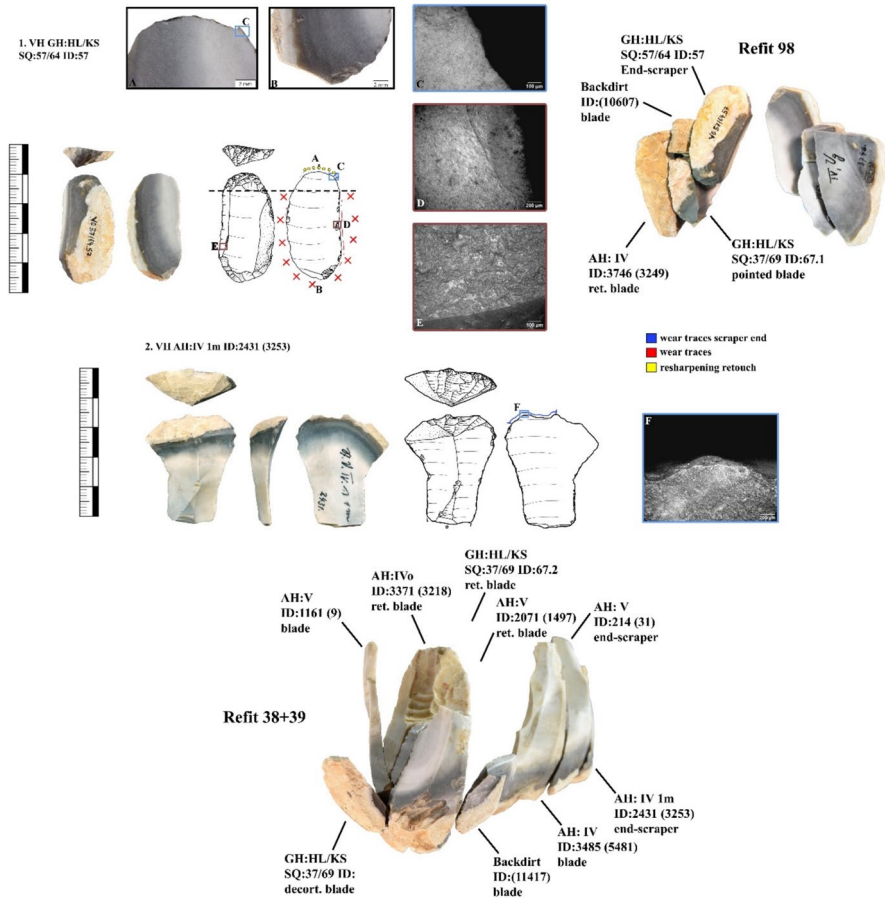


Fig. 9 End-scrapers of minimal raw material unit JH1d: (1) end-scraper (GH:HL/KS SQ:57/64 ID:57) that is part of refit 98: (A) resharpended scraper head with limit of the resharpening visible on the right side, ventral (12,5x); (B) intense hafting scarring at the base of the artifacts (8x); (C) rounding and polish on the limit of the last resharpening of the scraper head (200x); and (D) hafting scar associated with hafting bright spot, ventral (100x), several hafting bright spots next to the ridge with hafting scarring, dorsal (200x). (2) End-scraper (AH:IV ID:2431) that is part of refit 38 + 39: (F) developed rounding and flat polish on scraper head, ventral (200x) (photos and drawing: B. Schürch; micrographs: A–B. Olympus SZX7; C–F. Olympus BX53M)

of the refitted bladelets. If the bladelets themselves provided evidence of use, this was taken as additional evidence. The traces of use on the bladelets were most of the time ambiguous because possible traces of use were mixed with alteration, edge damage, and traces resulting from wet sieving (Table S1). Even though some bladelets showed signs of use, we could not always definitively interpret their function (Figs. 10 and S9–13). This needs to be further investigated in the future.

For the non-carinated artifacts interpreted as tools this was different. All three pieces showed evidence of use on the scraper head (Figs. 11 and S14–15). Two of

Fig. 10 Refit 107 from raw material unit JH1f: carinated end-scraper (AH:V 0 2 m ID:3134 (5251)) and refitted bladelet (backdirt collection seeberger ID:(11,378)): (A) Hammer polish and hammer striation, ventral (100x); (B) hammer polish, ventral (100x); (C) fine retouch, dorsal (16x); (D) sliced scars, ventral (16x); (E) platform remnant without use traces; (F) edge scarring, ventral (200x), one of two notched areas at proximal end, ventral (50x) (photos and drawing: B. Schürch; micrographs: C–D. Olympus SZX7; A,B,E–G. Olympus BX53M)

them also showed clear evidence of hafting (Figs. 11 and S15). The interpretation as tools is supported also by traces on the bladelets. In all three cases, bladelets showed traces of hide-working around the platform that match the traces on the end-scrapers. The bladelets did not show traces of use besides the ones around the platform.

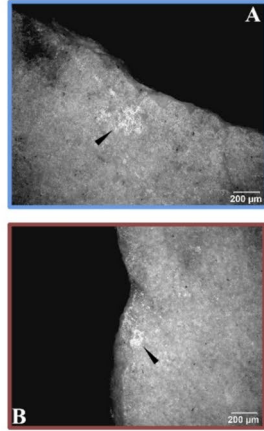
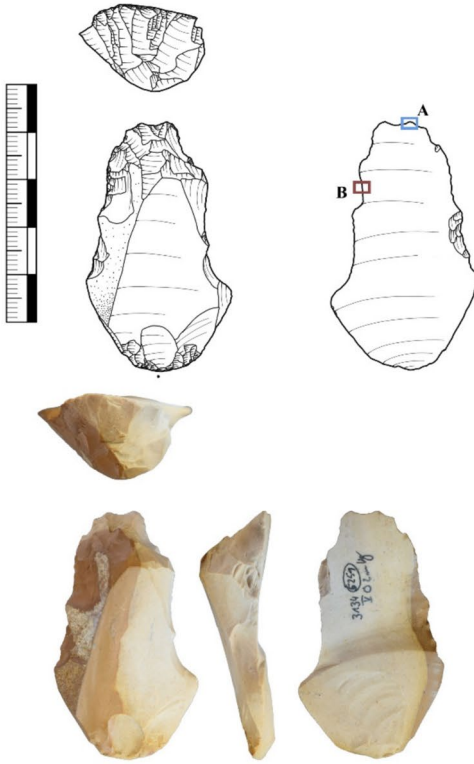
For the refits, pieces belonging to raw material units are present as well. This involves the unit JH1f (Figs. 10, S10, and S16), minimal raw material unit JH1u and JH1q. JH1f is not a minimal raw material unit, so it could involve more than one nodule. The characteristic brown coloration under the cortex, which can also be found in the bladelets, made the refits possible. Besides the three presented cores and the one unclear example, there is at least one end-scraper tool from the same unit (AH:V 4 m ID:670 (3528)) that is not presented in detail here (Fig. 3, 2). From JH1q, two pieces are present; one is interpreted as a core (Fig. S9) and one as a tool (Fig. 11). The raw material from JH1q is very characteristic and is interpreted as a minimal raw material unit. Besides the presented pieces, the unit contains several retouched blades, a pointed blade, end-scrapers, and splintered pieces. The carinated end-scraper and the end-scraper presented (Figs. S9 and 11) show that both cores and tools were produced from the same nodule. The same applies to unit JH1w. We therefore do not assume targeted production of blanks for either the production of bladelet cores or tools. An integrated production of these artifacts is more likely. Also, the core from the minimal unit JH1u (Fig. S11) and the presented end-scraper/pointed blades from the same minimal raw material unit (Figs. 6, S10, and S16) imply this.

Discussion

The data presented provides a complex picture. However, the chosen approach of dividing the artifacts into the two categories use or not used as tools allows us to clarify the picture. In order to get a much better understanding of the initial question (Fig. 1), the result of the traceological analysis must be shown together with the typological determination (Table 4). Note that the determination of whether the artifact is a carinated end-scraper (core) or an end-scraper (tool) is based solely on the results of the traceological analysis. The reason for this is that there is no standardized definition of these two terms, as described above. However, a statement can be made for carinated burins and nosed end-scrapers.

It is evident for the carinated burins, including the busked burins, that none of the examined artifacts show traces of use (Table 4). This applies both to the modified edge and to the ridges of the bladelet negatives. The possibility of use can therefore be ruled out. It can, therefore, be assumed that the carinated burins were only used

VH AH:V 0 2m ID:3134 (5251)



Refit 107



VH Backdirt Collection Seeberger ID:(11378)

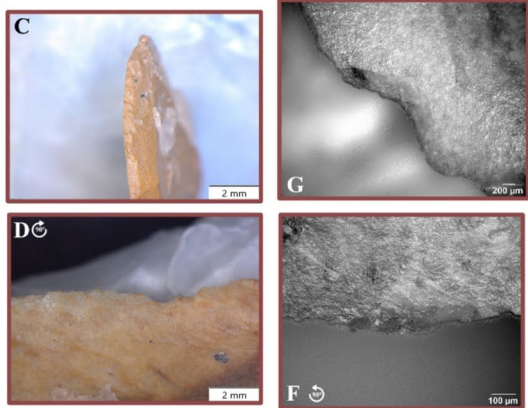
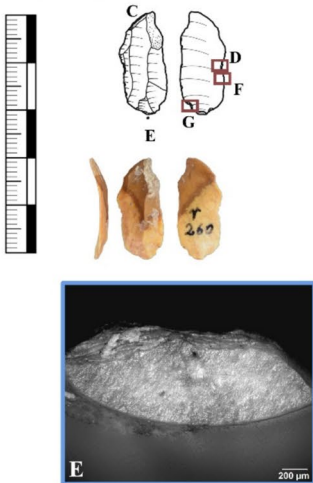


Fig. 11 Refit 136 from minimal raw material unit JH1q: End-scraper (AH:V ID:(S156)) and refitted bladelet (GH:HL/KS SQ:36/74 ID:88.1): (A) hide-working traces: polish and rounding, ventral distal (100x); (B) hide-working traces next to hammer traces: polish and rounding, ventral distal (100x); (C) hide-working traces next to hammer traces interrupted by resharpening: (100x); (D) hafting polish: haft polish and rounding, ventral (100x); (E) hafting polish: haft polish and rounding associated with scarring, ventral (100x); (F) hafting bright spot: hafting bright spot associated with scarring, ventral (100x); (G) platform remnant with incipient cracks and hammer polish (100x); (H, I) hide-working traces: developed rounding and polish on former scraper head and on the ridges of the retouch of the scraper head between ventral and dorsal (photos and drawing: B. Schürch; micrographs: A–I. Olympus BX53M)

as cores at Vogelherd. Traces of use of carinated burins as weapon tips (Dinnis et al. 2009) could not be observed in the Vogelherd assemblage.

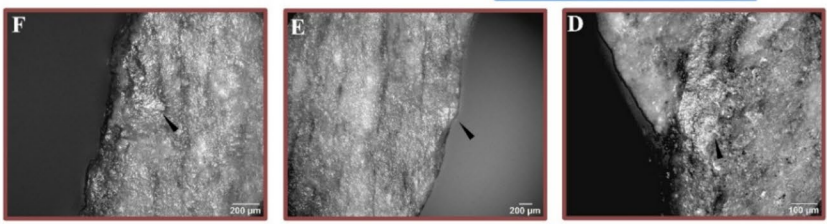
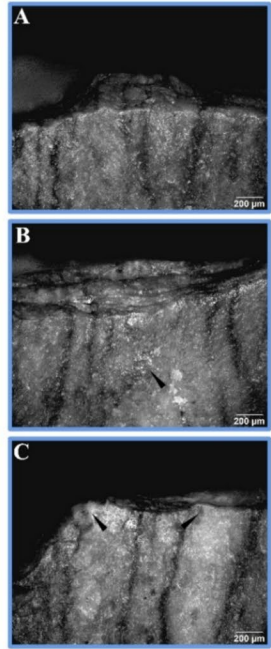
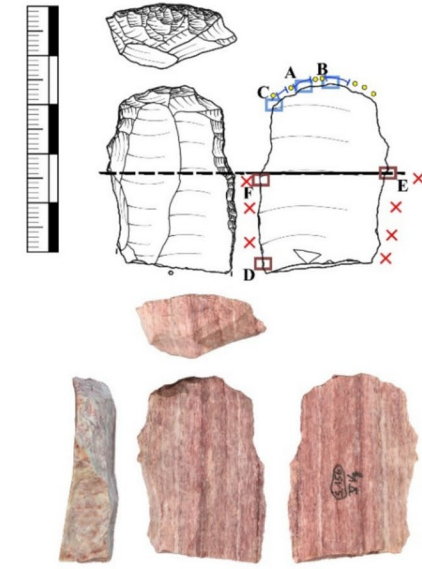
A different pattern emerges for the nosed end-scrapers. This type yielded both artifacts that were used and artifacts that were not used. This is not surprising, because the nose that distinguishes these artifacts from the other types can have different causes. Either the resharpening process can lead to the formation of a nose or the lateral preparation of the reduction surface of a carinated end-scraper. For this reason, nosed end-scrapers are usually classified as thick or flat, with the same subjective approach as carinated end-scrapers. In the case of nosed end-scrapers, however, there is a further uncertainty, because the definition of what a nose is and when an artifact has or does not have a nose depends on the researcher. In the case of nosed end-scrapers, this typological definition does not provide any indication as to whether these artifacts were used as tools or cores. In addition, the definition of these artifacts is subjective.

Since the two categories, carinated end-scraper and end-scraper, here, are based only on the results of the traceological analysis and not on a typological determination (not including the completely resharpened or unclear artifacts), we can now proceed to look for morphological criteria that distinguish the two categories from each other the best. The results of our morphological measurements previously showed that we have ten statistically significant attributes that could separate the two categories. The length of the blanks, although significant, is not included because it is not preserved in all the artifacts.

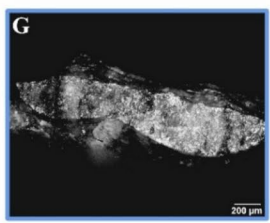
To visualize the two different groups, we performed a PCA (Fig. 12). The PCA shows that the artifacts used as tools (red) and the artifacts not used (blue) can be separated from each other fairly well. Only a few artifacts of the two groups are overlapping. The loading plot of the PCA shows that the artifacts that do not show traces of use as a tool show strong associations with several variables (width blank, thickness blank, width scraper cap, thickness scraper cap, length scraper cap, radius scraper cap, width largest bladelet negative, and length largest bladelet negative). The PCA plot also shows that the carinated and busked burins separate from the other artifacts, except one very large one; all of them plot together at the bottom center. It should also be emphasized that all but one artifact that was completely resharpened (black triangles) plot together with the used end-scrapers. This is an indication that these artifacts are also tools that no longer have any traces of use due to the resharpening.

The PCA is therefore a good indicator of how the artifacts vary morphologically. However, this only helps the analyst if they have the data set presented here or a

VH AH:V ID:(S156)



VH GH:HL/KS
SQ:36/74 ID:88.1



Refit 136

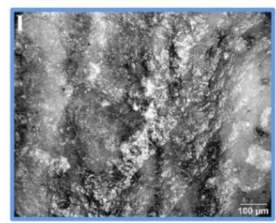
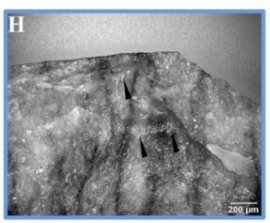


Table 4 Typological categories with information of use

Types	Used	Not used	Completely resharpened	Unclear	<i>n</i>	%
Busked burin		8			8	5.1%
Carinated burin		3			3	1.9%
Nosed end-scraper	3	3		2	8	5.1%
Carinated end-scraper		42			42	26.8%
End-scraper	79				79	50.3%
End-scraper/carinated end-scraper			6	11	17	10.8%
Total	82	56	6	13	157	100,0%

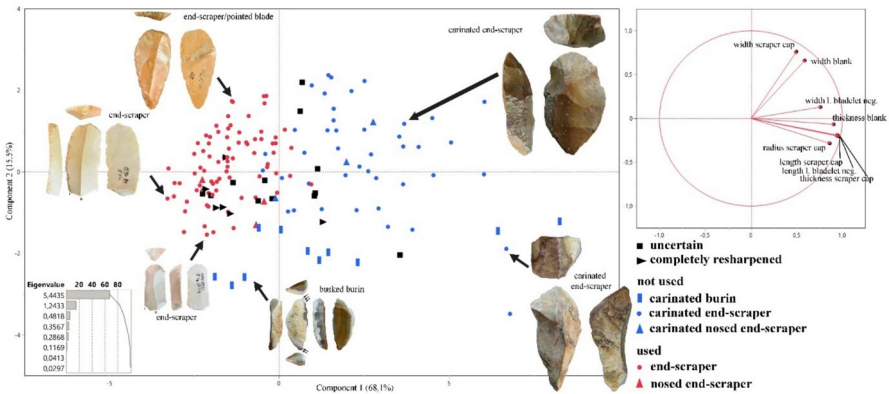


Fig. 12 PCA-plot of the morphological measurements ($n = 157$). Colors show the result of the traceological analysis. Loading plot (right) shows the included measurements and contribution to the dimensions 1 and 2. Scree plot (left bottom) shows the eigenvalue. Depicted examples of archaeological pieces are not in scale due to size limitation; the size only roughly indicates their original dimensions

similar dataset at their disposal. It would therefore be desirable to check whether individual measurements would also be sufficient to separate the tools from the cores. To do this, we use the boxplots of the individual measurements and compare which of the two groups offers the best separation. The traceological determinations of the nosed end-scrapers are included for this purpose. The carinated burins are not included, as these can be distinguished from the rest of the data set using typological and technological criteria without the support of morphological criteria and because the carinated burins use the width of the blanks and not the thickness for their reduction.

While all measurements visible in the boxplots yielded significant results for the distinction between used and unused artifacts (Fig. 13 and Table S2), the difference between the two groups appears to be most pronounced for the thickness of the scraper cap. If only the thickness of the scraper cap is taken into account, the two data sets are separated by a gap between 11 and 13 mm (Fig. S17). Taking this rough range as the boundary between tools and cores, there are only five outliers

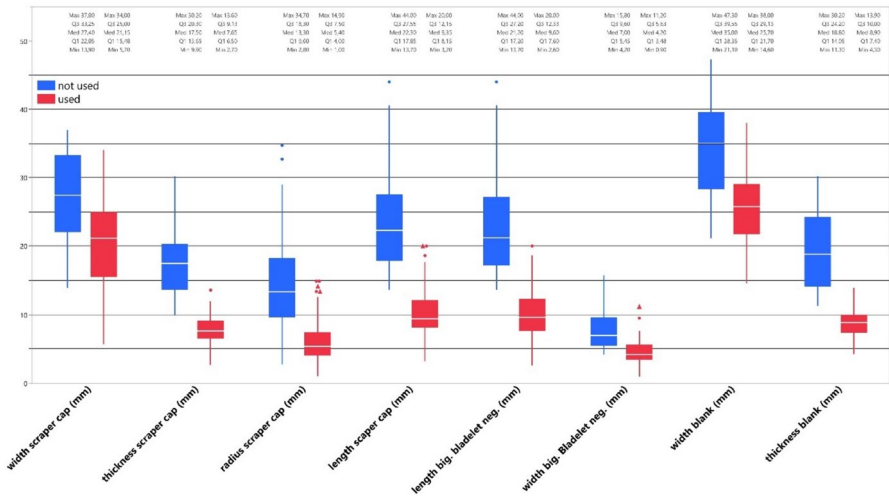


Fig. 13 Boxplots ($n=127$) of the end-scrapers/carinated end-scrapers not used as tools (blue) and artifacts used as tools (red). All measurements in mm besides the number of bladelet negatives (maximum, minimum, quartiles, median above the boxplots, for enlarged version of the data see table S2). Carinated burins and artifacts with the result “unclear” or “completely resharpended” from the use-wear analysis are not included here

from the 127 plotted artifacts (corresponding to a misclassification of 3.93%). Since a range is difficult to apply, it is appropriate to separate the two data sets at a value for the thickness of the scraper cap of 12 mm. Using the center between the means (midpoint), the two groups are separated at 12.72 mm (Table 5). This is supported by the quartiles of the boxplots. Q3 of the used artifacts lies at 9.13 mm and Q1 of the not used artifacts lies at 13.65 mm. However, since only a few artifacts are plotting in the range between 11 and 13 mm, with most cores clustering above and the tools below, it seems reasonable to choose 12 mm as the boundary between tools and cores (Fig. S17). This threshold of 12 mm for the thickness of the scraper cap is supported by ROC analysis, where the threshold is around the 11 to 12 mm value (Table S3). The ROC analysis also identifies the thickness of the scraper cap (AUC (area under the curve)=0.993), the length of the scraper cap (AUC=0.978), the length of the biggest bladelet negative (AUC=0.971), and the thickness of the blank (AUC=0.991) as attributes with excellent discriminatory power (Table S3).

The results, which are illustrated in Fig. 12 and Tables 5 and table S3, also have implications for our understanding of the requirements Aurignacian people placed on their tools and bladelet cores. The thickness of the scraper cap and the thickness of the blank both show similar trends. Two points can explain the differences between the tools and cores. Firstly, the production of bladelets requires a certain thickness of the scraper cap or the blank in order to obtain bladelets of a certain length. The same applies to the length of the scraper cap; if it is too short, only very small or no bladelets can be produced. For the length of the scraper cap, the threshold lies around 15 mm (Table S3). The thickness of the scraper cap and the blank play a different role for the tools. If the thickness of the blank or the scraper cap is

Table 5 Comparisons of the means of statistically significant measurements of end-scrapers (used as tools) and carinated end-scrapers (not used as tools). Carinated burins and artifacts with the result “unclear” or “completely resharpened” from the use-wear analysis are not included here

Results	Group	<i>n</i>	Mean	Center	Standard deviation	Standard deviation of mean	<i>P</i> -value
Blank							
Width in mm	Used	82	25.79	30.11	5.25	0.58	<0.001
	Not used	45	34.43		6.92	1.03	
Thickness in mm	Used	82	8.89	14.05	2.08	0.23	<0.001
	Not used	45	19.22		5.01	0.75	
Scraper head							
Width in mm	Used	82	20.52	23.91	6.09	0.67	<0.001
	Not used	45	27.30		6.36	0.95	
Thickness in mm	Used	82	7.73	12.72	1.95	0.22	<0.001
	Not used	45	17.70		4.84	0.72	
Radius in mm	Used	82	6.05	10.40	3.39	0.37	<0.001
	Not used	45	14.75		7.33	1.09	
Length in mm	Used	82	10.23	16.81	3.42	0.38	<0.001
	Not used	45	23.40		6.89	1.03	
Number of bladelet negatives	Used	82	3.33	4.71	2.31	0.26	<0.001
	Not used	45	6.09		2.98	0.45	
Length biggest bladelet negative in mm	Used	82	10.18	16.37	3.51	0.39	<0.001
	Not used	45	22.56		7.04	1.05	
Width biggest bladelet negative in mm	Used	82	4.51	6.11	1.79	0.20	<0.001
	Not used	45	7.72		2.80	0.42	

too large, it can be more difficult to haft the artifact. The sample that was analyzed for hafting traces showed that hafting is not uncommon in the assemblage. It therefore seems likely that a significant proportion of the end-scrapers were used hafted. The requirements for tools and cores are therefore opposed in the case of thickness, which makes it possible to distinguish between the two groups. The width of the scraper cap and the blank also differ significantly (Table 5), which can most likely be explained by the fact that thicker blanks were used for cores and thinner blank shapes for tools, which indirectly also influences the width. Unlike the thickness, the width can be easily adjusted by retouch. The difference in the radius of the scraper head (Table 5) could be explained by the fact that the resharpening of the edges has resulted in a steeper scraper head. However, this is not reflected in the angles of the edges. One explanation for this is that the angle measured at the edge does not reflect the condition of the entire scraper head, but only the angle of the negatives close to the edge. The radius of the scraper head is thereby an indirect indicator of the intensity of the resharpening.

The length of the blank, not listed in the boxplot, would certainly also be a good indicator for the selection of blanks. However, these were not included

here as this would reduce the size of the sample. Although the length resulted in statistically significant values, this is a clear underestimation, as the tools lose more and more length through repeated resharpening (Gallagher, 1977). This is also made clear by the refits in the minimum raw material units. If the tools were preserved in their original, non-resharpened state, the difference would probably be even clearer. Concluding these results, there is a clear morphological separation between tools and cores using the thickness of the scraper cap. This can be explained by the different demands placed on the tools and cores. This proposed separation can best be broken down to the thickness of the scraper cap and a threshold of 12 mm.

The results also have implications for our knowledge of the desired bladelets. However, as we only measured the largest bladelet negatives, it is possible that the threshold is somewhat too high here. Since most of the cores in question are probably cores at the end of the reduction process, this effect may be compensated for. However, this problem cannot be solved without further investigation of the bladelets, as the smaller bladelet negatives could be target products as well as preparation or resharpening. With the available results, the threshold for the length of the bladelets is around 15 mm and for the width 5 mm (Fig. 13 and Tables 5 and S3). The length of the bladelets largely corresponds to the length of the scraper cap. We therefore assume that the reduction of the bladelets was aimed at blanks that were at least 15-mm long and 5-mm wide, or larger.

As the number of bladelet negatives, the length and width of the bladelets are also indirectly derived from the dimensions of the scraper cap. The picture here is similar to the previously mentioned measurements (see Table 5). However, it must be pointed out once again that smaller bladelets are also produced on the tools. Here, the threshold between cores and tools is around five bladelet negatives (Table S3). This implies that you are likely dealing with a core if you can observe five or more bladelet negatives on your piece. However, a technological definition that refers to the existence of bladelet negatives alone may not be very helpful when it comes to the question of tool or core. Including maintenance operations (Aleo et al., 2021; Chiotti, 2000; Falcucci & Peresani, 2018; Hahn, 1988; le Brun-Ricalens & Brou, 2003; le Brun-Ricalens et al., 2005) in the definition of cores can be useful. In the studied assemblage, the preparation of the platform only occurs with cores and therefore seems to be a good indicator to identify cores. Maintenance operations on cores may not always be present. Technology is therefore only a one-sided argument.

To come back to the different scenarios for the technotypical definition of bladelet cores and end-scrapers, we can now conclude the following:

- Carinated burins (including busked burins) did not show any traces of use; therefore, the typological category can be used as an indicator for their function.
- The typological category of nosed end-scraper or nosed carinated piece reflects the position in the *chaîne opératoire* and does not add to our understanding if they are cores or tools.
- The separation of cores and tools by their thickness, which was often postulated before, seems to be useful. However, without a value where to separate the two groups, this definition is useless and prone to observer bias.

- Technological definition can help to distinguish cores from tools. This includes, for example, the preparation of the platform. However, the absence of these technological features is not necessarily informative.

Additionally, it needs to be considered that artifacts can have a dual function and changes in their use life (Binford, 1979; Dibble et al., 2017; Jelinek, 1976). We tried to resolve this by integrating refits into our analysis. However, these refits only give insights into the last phases of the artifacts' use life. Therefore, the use of bladelets coming from the earlier phases of reduction or resharpening as tools cannot be excluded.

Equally, it is also possible that cores were used as tools from time to time during their use life. In most cases, this is difficult or impossible to verify. An accumulation of such cases is, however, contradicted by the fact that the morphological examination showed clear differences between the used and unused artifacts.

Applying the 12-mm Threshold to the Aurignacian Assemblage of Vogelherd and Its Implications

The application of the 12-mm threshold and the determination that carinated burins are cores, to the Aurignacian assemblage of Vogelherd (IV and V, $n=5710$) results in the presence of 163 carinated pieces, with 185 ends (Fig. 14). Of the 185 ends, 145 are carinated end-scrapers and 31 carinated burins. There are 536 end-scrapers with one single modified end (one scraper head), and 271 end-scrapers where a scraper head is combined with a second tool end. All combined, there are 145 carinated end-scrapers, 40 carinated burin ends, and 915 end-scrapers, resulting in 1.296 tool and core ends in our database (Fig. 14). For 1174 ends, width and thickness of the blank and width and thickness of the scraper end/carinated burin end were recorded. The other statistically significant attributes were not recorded for the whole assemblage. By applying the 12-mm threshold to our dataset and by comparing the size of the scraper head with the size of the blanks, we can make the following observations. Around the 12 mm threshold or the 11–13 mm boundary of the scraper head, the dataset slowly starts to fan out. For the blank size, it is visible that the thickness of the blanks that are under the 12-mm threshold (of the scraper head) are hardly ever over 18-mm thick. If we compare the distribution of the carinated burins, we notice that they are mostly present at the lower side of the concentration. They are also present at the lower concentration of the scraper heads under 12-mm thickness. This could imply that the shapes present there, with a low width and relatively high thickness of the scraper head, are well suited to produce very small bladelets. From this area, we only analyzed a few artifacts in this study, but it could be worthwhile to investigate this in more detail.

Applying the other thresholds (Tables 5 and S3) to the entire assemblage is not possible at the moment because not all measurements were recorded on all scraper heads. Comparing the size of the bladelets would be very interesting; however, as Vogelherd was excavated in 1931 and the material was not sieved, only 193 bladelets are preserved in context, and these are mostly on the larger side. Therefore, such

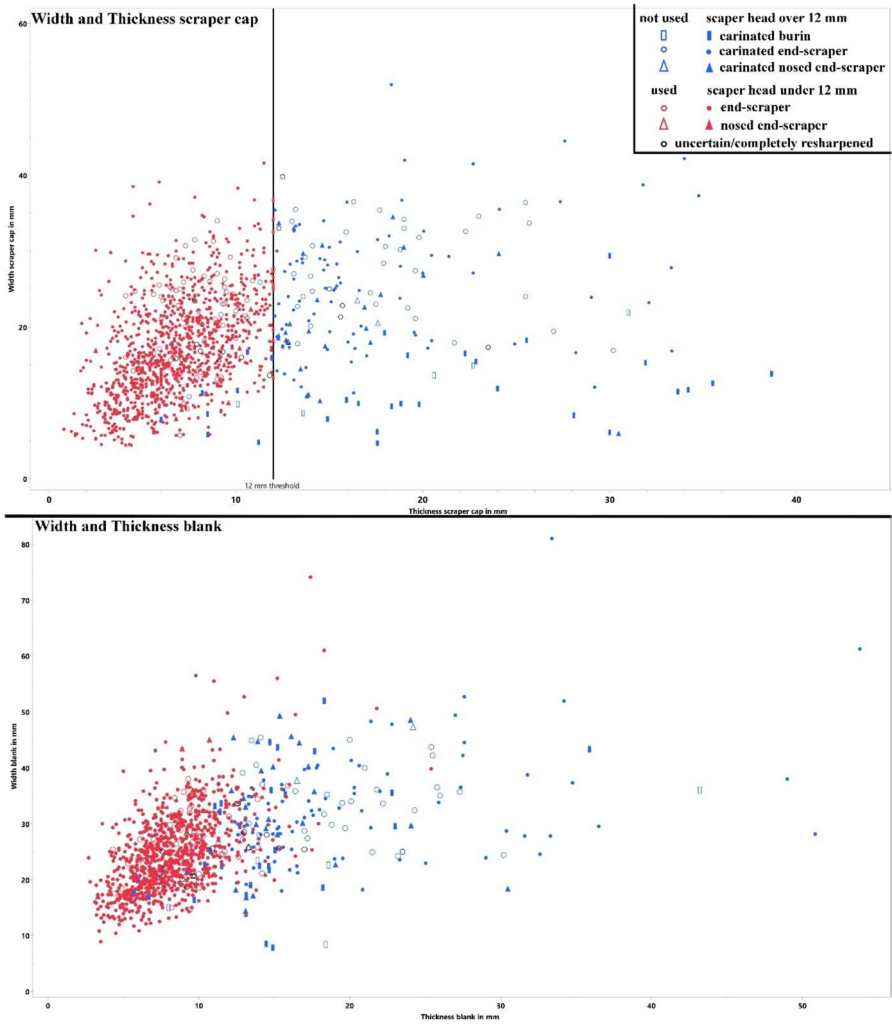


Fig. 14 Distribution of the thickness and width of the scraper head with the 12-mm threshold; distribution of thickness and width of the blanks (bottom); artifacts studied for use traces are displayed with the hollow symbols, and the artifacts not analyzed for traces (AH IV and V) are displayed as filled symbols. For the artifacts not analyzed for traces, the 12-mm threshold of the thickness of the scraper head is applied to separate the dataset into tools and cores

an analysis would be more appropriate at a site where bladelets were recovered more meticulously.

Conclusion

The technofunctional study presented here reflects the most comprehensive analysis to date addressing the long-running debate about the potential separation of carinated cores and end-scrapers in the Aurignacian. This research focuses upon traceological results on 128 artifacts with implications for the whole assemblage of 807 end-scrapers and 163 carinated cores (definition based on the 12-mm threshold that resulted from the traceological analysis) from the archetypal site of Vogelherd Cave in the Lone Valley of the Swabian Jura. Additionally, we present several refitting sequences including either end-scrapers or carinated cores with refitted bladelets. Our technofunctional analysis allows us to distinguish between the deliberate production of bladelets as blanks for microlithic tools and bladelets as well as small flakes that resulted from resharpening end-scrapers. These end-scrapers frequently preserve clear use and hafting wear, enabling us to trace the reduction of the working edge of the scrapers to near the limit of the haft (Fig. 7). Both the end-scrapers and resharpening flakes document unambiguous evidence for hide-working. In contrast, the carinated cores lack such use traces as do the bladelets produced from these cores. These technological adaptations of Aurignacian knappers represent behavioral innovations that are lacking in the preceding late Middle Paleolithic of the Upper Danube region and in the Middle Paleolithic in general (Conard & Bolus, 2006, 2003, 2008; Nigst et al., 2014; Uthmeier, 2004).

Given the large sample size of this study and the clarity of the results, we believe we have identified robust criteria for separating end-scrapers and carinated cores. At Vogelherd, carinated cores typically have reduction surfaces of 12 mm or thicker producing bladelets with a length of 15 mm or longer, while end-scrapers nearly always are thinner than 12 mm. This observation is consistent with the mechanics of hafting and the ergonomics of using the tools. Extremely thick end-scrapers become difficult to haft and use for hide-working and similar purposes. On the other hand, Aurignacian knappers rarely used reduction surfaces thinner than 12 mm to produce blanks.

This threshold does not imply that the resharpening of the tools never produced small bladelets that could also be utilized or modified. Rather, this research demonstrates that the design of the tools and the cores differs and can be retraced by combining use-wear with morphological data. Future comparative studies should be able to test whether or not this value of 12 mm can also be applied to other Aurignacian assemblages to separate artifacts that served primarily as cores versus ones that served as end-scrapers that were primarily used for hide-working.

This work builds on earlier research in southwestern Germany on refitting and technofunctional analysis, as well as on issues related to the microlithization of Aurignacian tool kits (Bataille & Conard, 2018; Bataille et al., 2018; Hahn, 1977, 1988). Our ongoing work seeks to move deeper into the realm of Aurignacian micro-technology to determine how lithic, botanical, osseous, and soft-tissue technologies

articulated during the early Upper Paleolithic. Based on our current understanding of late Middle Paleolithic technology, with few exceptions (e.g. Conard, 1992) Neanderthals, while highly skilled knappers with variable and diverse technologies, rarely employed microlithic approaches to problem solving. Some of these Aurignacian innovations appear to be novel adaptations that may have had important implications for the success of early modern humans in southwestern Germany and over much of western Eurasia. Although a wide range of symbolic artifacts, including three-dimensionally formed personal ornaments, figurative depictions, therianthropomorphic imagery, and musical instruments (Conard, 2010; Conard et al., 2015a, b) are often viewed as key features of the Aurignacian behavioral repertoire, the large number of innovations in lithic, osseous, and presumably botanical technologies (Conard & Rots, 2024; Hahn, 1977; Kitagawa & Conard, 2020) accompanied what appears to have been a shift into a world characterized by symbolic communication and more complex social networks (Vanhaeren & d'Errico, 2006). In this way, our research calls for a stronger focus on highlighting the intersection of the technological, social, and symbolic realms of Paleolithic life. This approach will help to contextualize how and why Aurignacian populations expanded demographically and geographically across western Eurasia, while the earliest modern humans in Europe seem to have gone extinct without contributing to the genetic makeup of later populations (Hublin et al., 2020; Mylopotamitaki et al., 2024; Prüfer et al., 2021; Smith et al., 2024).

Competing interests

The authors declare no competing interests.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s10816-025-09728-2>.

Acknowledgements We would like to thank Mohsen Zeidi and Alexander Janas for their work at Vogelherd, as well as the technicians and excavators. Research at Vogelherd was supported by the University Tübingen, the Verein für Eiszeitkunst im Lonetal, the Ministry of Science in Baden-Württemberg, the city Niederstotzingen and the Senckenberg Centre of Human Evolution and Palaeoenvironment. The authors would like to thank the two anonymous reviewers for their helpful comments, which improved the manuscript considerably.

Author Contribution B.S. and V.R. contributed to the study's conception and design. B.S. wrote the initial draft of the manuscript text and prepared figures and tables. All authors reviewed the manuscript. N.J.C. conducted research fieldwork at the site Vogelherd. N.J.C. directed the scientific research projects at the forementioned site.

Funding Open Access funding enabled and organized by Projekt DEAL.

Data Availability No datasets were generated or analysed during the current study.

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