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On Making of Micoquian Bifacial Backed Tools at Pietraszyn 49a, SW Poland

Andrzej Wiśniewski[1] · **Marcin Chłoń**[1] · **Marcel Weiss**[2] · **Katarzyna Pyżewicz**[3] · **Witold Migal**[4]

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Abstract
This paper attempts to show that manufacture of Micoquian bifacial backed tools was structured. Data for this study were collected using a comprehensive analysis of artefacts from the site Pietraszyn 49a, Poland, which is dated to the beginning of Marine Isotope Stage 3. Based on the whole data set, it was possible to distinguish four stages of the manufacturing process. During manufacturing, both mineral hammer and organic hammer were used. The tools were usually shaped due to distinct hierarchization of faces. The study has also shown that the shape of bifacial tools from Pietraszyn 49a is very similar to the other Micoquian examples from central Europe. The ways of shaping of some tools are finding their counterparts also in the Early Upper Palaeolithic inventories, but the similarities are rather limited to the narrow range of preparation of bifacial form.

Keywords Bifacial tools · Central European Micoquian · Technique · Manufacture stages · Hierarchization

Introduction

Since the recognition of the Central and Eastern European Micoquian (CEEM), methods of manufacturing bifacial tools have been addressed in a variety of publications (Bosinski 1967, 1969, 2000–2001, 2006; Burdukiewicz 2000; Chmielewski

✉ Andrzej Wiśniewski
andrzej.wisniewski@uwr.edu.pl

[1] Institute of Archaeology, University of Wrocław, Wrocław, Poland

[2] Department of Human Evolution, Max Planck Institute for Evolutionary Anthropology, Leipzig, Germany

[3] Faculty of Archaeology, University of Warsaw, Warszawa, Poland

[4] The State Archaeological Museum, Warszawa, Poland

1969; Desbrosse et al. 1976; Kozłowski 1972; Kozłowski and Kozłowski 1977; Kozłowski and Kozłowski 1996; Krukowski 1939-1948; Koulakovska et al. 1993; Mania and Toepfer 1973; Richter 1997; Sobczyk 1975, 1992; Valoch 1988; Veil et al. 1994 and others). Initially, this was only brief mentions, then gradually replaced by discussions on the formal classification of bifacial tools. However, some exceptions could be found, for example comments on the change of the morphology of Pradnik knives (Krukowski 1939-1948), or the definition of a unique way of Micoquian tool shaping: *wechsel-seitig-gleichgerichtete Kantenbearbeitung* = alternating unidirectional edge reduction (Bosinski 1967), or the formation of active parts on tools by tranchet blows (Krukowski 1939-1948; Kowalski 1967; Jöris 1992). Starting from the mid-1990s, attempts on more detailed characteristics of production stages considering structural models of operational chains were made (Boëda 1995; Demidenko 2015; Gouédo 2001; Bataille 2017; Frick and Floss 2017; Frick et al. 2017; Iovita 2014; Jöris 2001, 2006; Kurbjuhn 2005; Migal and Urbanowski 2006; Pastoors 2001; Sudoł 2013; Uthmeier 2016; Uthmeier and Chabai 2010).

Despite the growing number of publications dealing with a structural approach to the problem of bifacial tools, numerous unsolved problems await a more in-depth discussion, including investigations on early stages of thinning, the shaping of bifacial tools, and the dynamics of the production processes. Gaps in our understanding also include an assessment of the techniques applied in the manufacture of a bifacial tool, a more precise specification of shaping, and modification stages. Some of these aspects have been discussed in the context of single sites (Frick and Floss 2017; Neruda and Kaminská 2013), but such conclusions have been based on the analysis of flake scars of intensively reduced artefacts. In this situation, much information on the early stages of tool shaping could not be retrieved. The gaps in our understanding become even more pronounced when the state of analysis of Micoquian technology is confronted with that of the analysis of somewhat older or younger bifacial technologies which were analysed in more detail (Apel 2001; Aubry et al. 2008; Austin 1994; Bradley and Sampson 1986; Bradley et al. 2010; Callahan 1996; Gowlett 2006; Moore 2015; Stout et al. 2014; Wenban-Smith 1999 and others).

This paper attempts to show that the manufacturing process of CEEM bifacial backed tools was structurally complex despite the more flexible approach to the lithic raw material. It was governed by certain principles within which the most important was hierarchization of tool geometry and distinguishing techno-functional units sensu E. Boëda and M. Lepot (Boëda 2001, 2013). Moreover, we want to demonstrate that the dynamics of tool shaping varied considerably. Next to modestly shaped forms, pieces resulting from a very material-consuming reduction are found. Additional examples indicate a radical change in the concept of the tool production. In our opinion, the issues mentioned above are within the scope of interest of Micoquian technology of central and eastern Europe and provide a basis to reconsider the connection with later industries of the Early Upper Palaeolithic (EUP), which are regarded as continuation of the Micoquian within the endemic model (see Mester 2018; Neruda and Nerudová 2009).

We try to solve the above-outlined problem of the reconstruction of consecutive stages and techniques applied, based on the material from the CEEM site Pietraszyn 49a, SW Poland, a well-preserved and representative collection in terms of illustrating consecutive stages of transforming the lithic raw material. The fact that most of the artefacts from Pietraszyn 49a can be correlated with a mass production of bifacial tools in a workshop associated with hunting activity (Wiśniewski et al. 2019) is of decisive significance. The optimal state of preservation of the set located in low-energy sediments of a river valley makes it possible to perform a refitting study. Multi-part groups of refits enable us to place waste and artefacts in a spatio-temporal context and thus enables a precise observation of performed working stages. This leads to an assessment of the effect of various techniques compared with conclusions based exclusively on scar pattern analysis. Additionally, we used also the classic analysis of flake scar quality, microscopic technological analysis with an investigation of potential damage during the manufacturing of bifaces, and elliptical Fourier-based outline analysis of the finished tools.

Material and Methods

Material

The site Pietraszyn 49a is located in the southern part of the Głubczyce Plateau (Fig. 1), approximately 14 m above the recent bottom of the Troja River valley (218 masl). The remains of human activity were recorded in a layer of sand and silt (B9) which belong to the sediments of the paleo-river bank. Systematic field works on 24 m^2 provided almost 19,000 lithic artefacts. The density of artefacts can be described as very high (610 pieces per square meter). The assemblage comprises flakes (16.5%), blades (1.15%), chips (80.7%), debris (0.64%), raw material (0.24%), preforms (0.03%), tool wastes and undetermined (0.22%), and retouched tools (0.5%). The remnants of clusters associated with human workplaces were also preserved. We have recognised the traces of four clusters so far. Within them, we noticed numerous refits of lithic artefacts. Artefacts from Pietraszyna 49a are dated with OSL of feldspar (pIRIR225-dating approach) to 60 ± 6 ka, which places the site chronology in the late MIS 4 or the beginnings of MIS 3 (see Wiśniewski et al. 2019). At Pietraszyn 49a, we found fragments of mammoth teeth, a fragment of the upper tooth of woolly rhinocerous, and several fragments of the horse's cheek teeth (personal information of K. Stefaniak, 2018). The connection of palaeontological materials with human activity remains unresolved because of the fragile state of preservation.

Methods

Manufacturing Stages

The aim of this study is to investigate the material modifications during the manufacture of bifacial backed tools. A similar work on analysing CEEM materials was undertaken by researchers involved in the studies on the Middle Palaeolithic of the Crimea (e.g. Uthmeier and Chabai 2010). The approach adopted here departs from the traditional typological classification in favour of the assessment of artefacts in terms of intentional operations of the manufacturers.

We selected 62 objects, covering the complete operational chain of stone tool production: lumps of raw material in various stages of (pre-) processing through tools reduced at the site and/or imported from outside the site. Especially, representative

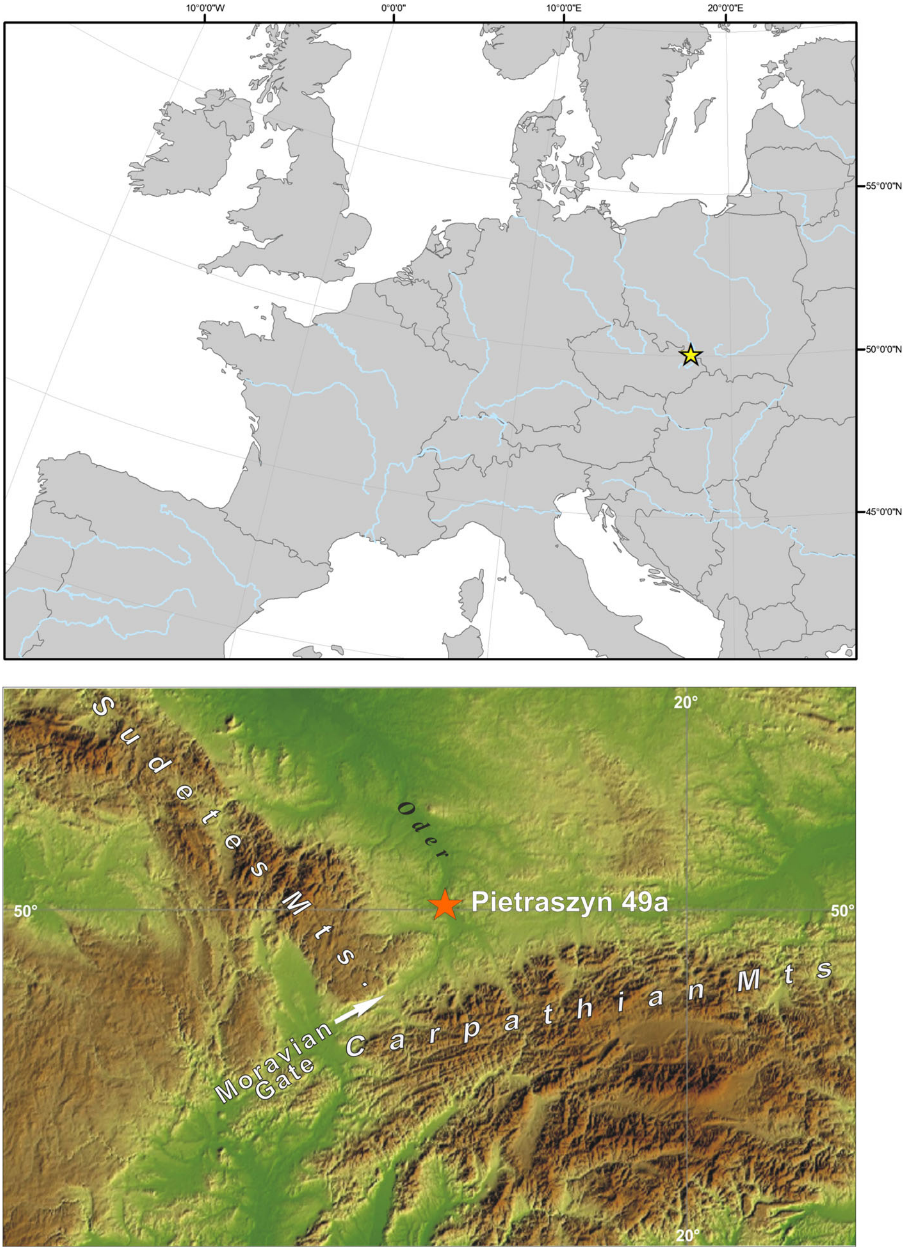


Fig. 1 Location of Pietraszyn site 49a

groups of refits were considered. Below we present the division mentioned above (Fig. 2). It should be borne in mind that in this case, the degree to which various classes are representative is unimportant.

a.1. Lack of traces of reduction: raw material

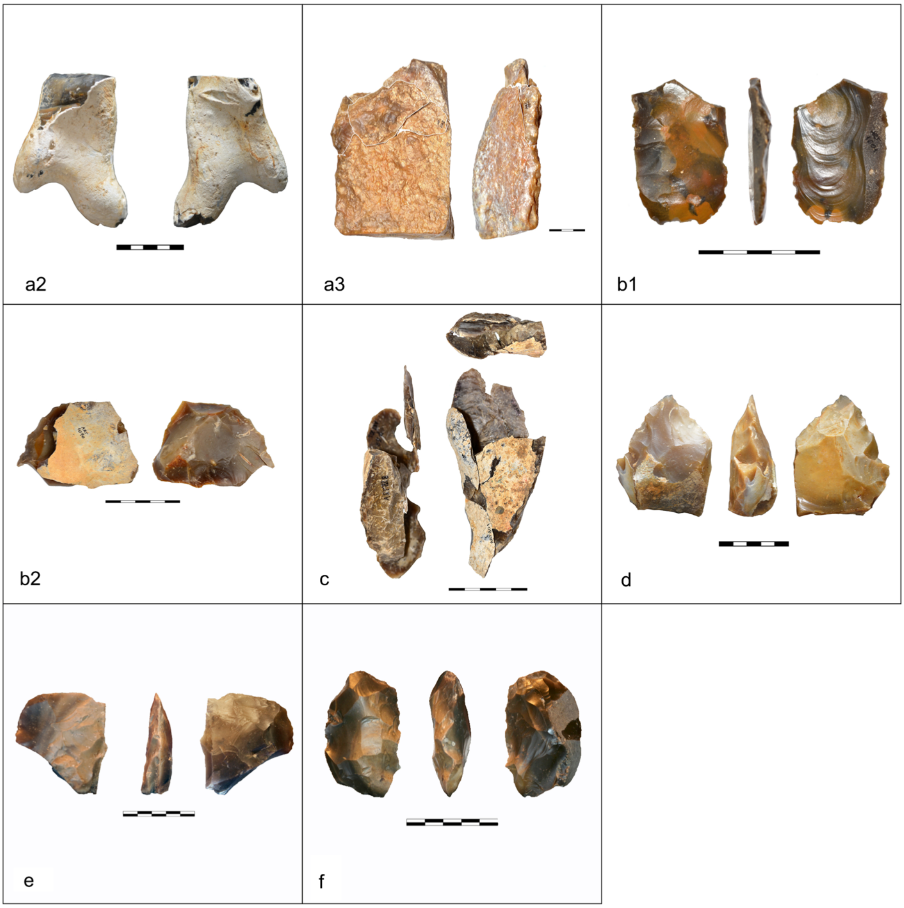


Fig. 2 Classification of artefacts in terms of stage of modification during the manufacturing of bifacial tools (description of classes in the text). Figures a3 and c present groups of refits

a.2. Single, isolated scars
a.3. Nodules divided along weathering cracks
b.1. A row of scars on one side
b.2. Striking platform and traces of detachment of single flakes
c. Forms with signs of side hierarchization
d. Forms with traces of regularisation and isolation of main parts, e.g. base, back, tip, and cutting edge(s)
e. Finished forms
f. Reduced forms transported to the site
g. Unidentified fragments

The next aspect of our analysis was to ascertain the exposure of the envisioned tool in the block of raw material (Fig. 3). We tried to ascertain which parts of the natural lump/nodule/chunk did not undergo processing. We assumed that the cortex or earlier

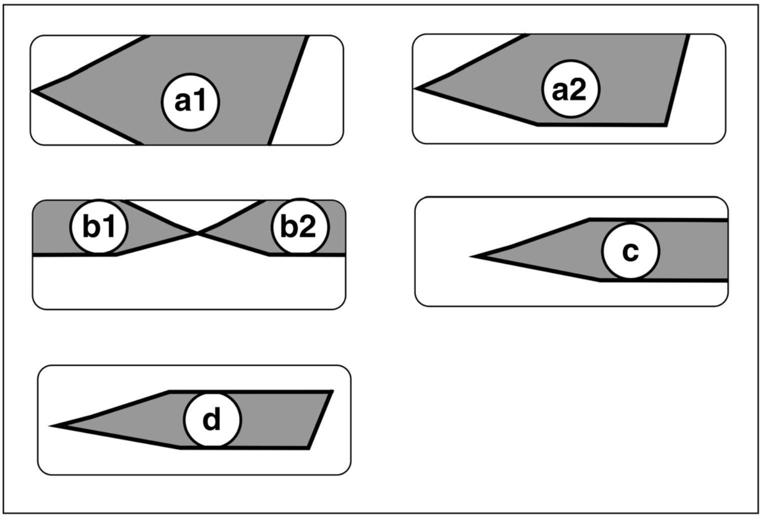


Fig. 3 Exposure of bifacial tool in the block of raw material: transverse sections

non-anthropogene surfaces constituted the natural surface. Cracks resulting from breaking of a frost-damaged nodule by the knapper were not regarded as natural. This enabled us to discuss the raw material selection, i.e. to what extent it was aimed at collecting natural flat forms that did not require extensive reduction. We distinguished four variants of exposure and several sub-varieties. The least modified objects were represented by variant A, the most modified forms were variant D, with traces of reduction visible on all parts of the tool. In theory, the latter group may include objects modified during use and not as a result of preparatory reduction. As a rule, it is possible to discern such objects (see, e.g., Richter 2005), but sometimes re-modification may result in large scars that imitate the initial stage of shaping (for a model of these changes see Migal and Urbanowski 2006). However, the analysed set includes only few such objects. All technological aspects suggest their formation within the workshop (3 objects).

Microscopic Analysis of Hammer Type

The possibility of the spatial location of wastes (Fig. 4) and tools in the sequence of refits resulting from bifacial tool manufacturing in Pietraszyn 49a encouraged us to perform a more detailed analysis of the problem of flake detachment. As a continuation of microscopic and macroscopic analyses, started earlier by one of the authors (K.P.) (see Wiśniewski et al. 2019), we selected the best represented groups of refits which included either relatively long overlapping flake series or groups which were accompanied by chunks and tools.

The analyses were done using a metallographic microscope Nikon LV150 and digital microscope Keyence VH-Z100R. Prior to the analysis, the flint material was cleaned with warm water with detergent and acetone. Technological traces, mainly in the form of linear traces and polishes, were examined under magnifications of × 50 to × 400. The observations were compared with the existing knowledge of microscopic traces acquired during the production of flint objects (Byrne et al. 2006; Ibáñez et al. 1990; Keeley 1980, 28–29; Moss 1983, 104; Pyżewicz 2013; Rots et al. 2011;

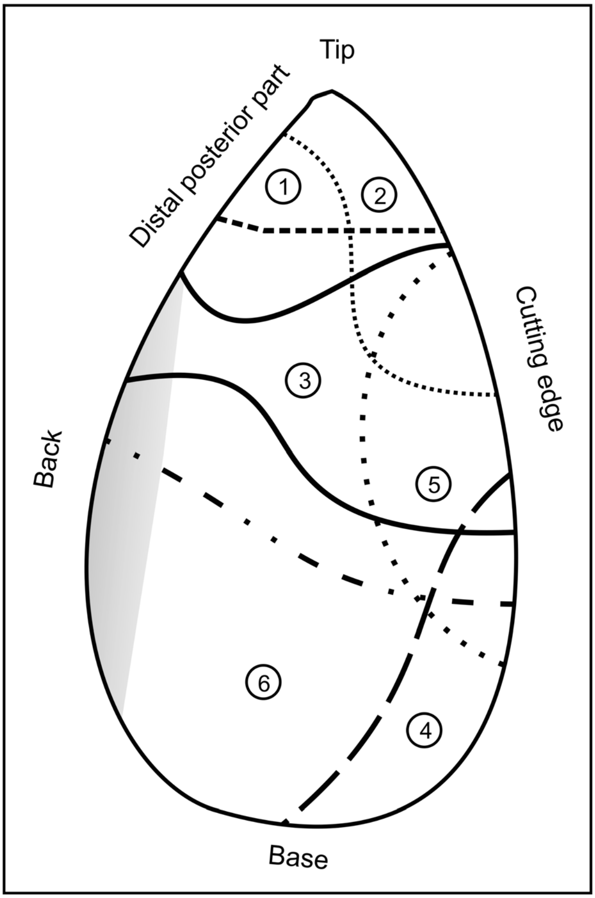


Fig. 4 The schema shows the place of various wastes that were recognised in the assemblage from Pietraszyn 49a

Vaughan 1985, 41–42; Vergès and Ollé 2010). More importantly, the observed traces were verified with the experimental reference collection of the Faculty of Archaeology, University of Warsaw instead of Institute of Archaeology, Adam Mickiewicz University/Poznań. The collection includes more than 100 series associated with knapping of flint, using potential Palaeolithic percussion techniques like the use of mineral hammers, antler, and wood.

The microscopic analyses focused on the surface of butts, the dorsal sides of flakes, and the striking platforms of tools. These are the areas of the potential occurrence of microscopic technological traces. A detailed analysis of the morphology and location of microtraces may provide a clue to their origin. The first trait (trace morphology) corresponds mainly to the raw material used to manufacture the tool, that is, for example, mineral material, antler, or bone.

The location of technological microtraces indicates the trajectory of the tool. On this basis, it can be concluded whether the traces result from a detachment from the analysed object, and then they are usually located at the point where the force was applied, or from the application of additional procedures, for example grinding of edges, retouching, or faceting of the striking platform—in such cases traces will be visible in corresponding places: in the region and on edge between the flaking surface and the striking surface.

In this context, it is worth mentioning that the frequency of the appearance of technological microtraces is associated with the tools applied. In the case of mineral hammer use, microtraces were observed on most experimental objects. About half of experimental objects made with antler tools show no distinctive microscopic traits.

Scar Pattern Analysis of the Finished Tools

Another aspect of our analysis was the technological description of both sides of the finished tools. This was done by analysing the proportion of scars of flakes resulting from thinning and shaping, as well as edge regularisation (Fig. 5). We selected 7 kinds of scars, which were described earlier, among other authors by Gouédo (2001), Bradley et al. (2010), Callahan (1996), and Richter (2013): (1) overlapping, including full-face; (2) overshot scars; (3) diving scars; (4) distal and (5) proximal end-thinning scars; (6) invasive-short; and (7) marginal. It should be pointed out, however, that overlapping scars which include the whole surface and are associated with the removal of overshot flakes have a less regular character than the scars resulting from manufacturing of, e.g., Late Palaeolithic blades because of the different approach to shaping. These are, among

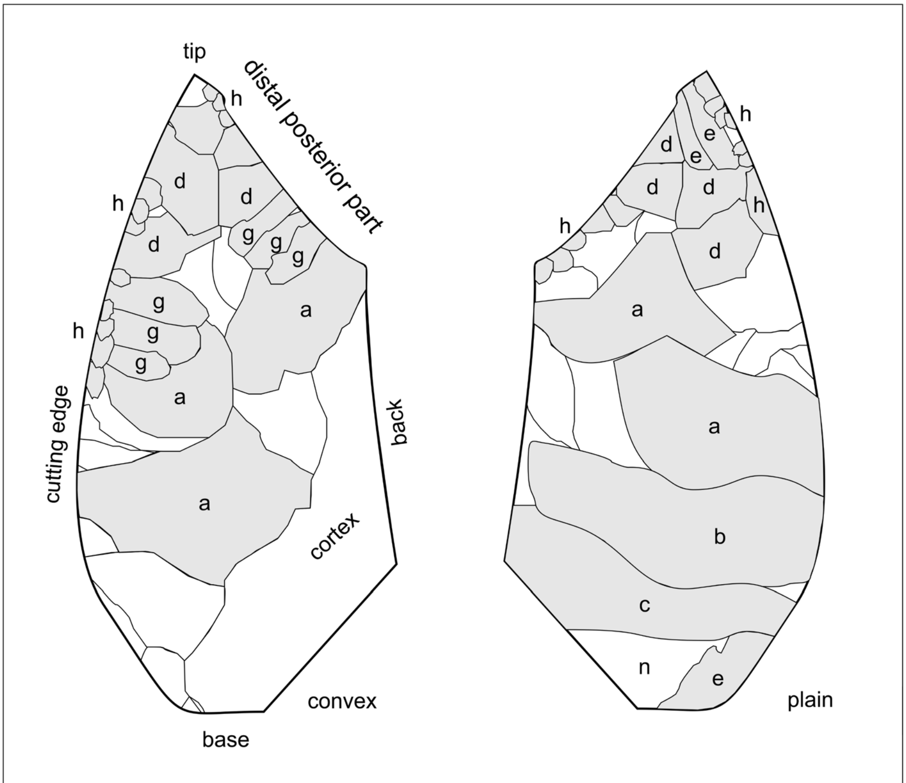


Fig. 5 Types of flaking on convex and plane face of the bifacial tool. (a) Overlapping. (b) Full-face. (c) Overshot. (d) Diving. (e) Distal and proximal end-thinning. (g) Invasive-short. (h) Marginal. The comedial flaking (f) has recognised at Pietraszyn 49a (see Bradley et al. 2010, Fig. 3.11)

others, the configuration of the striking platforms, and the hammers and materials used (e.g. Aubry et al. 2008; Bradley et al. 2010).

We analysed the contours of flakes recorded for the refits separately for each side which provided a more complete picture of the sequences of scars. Usually, morphometric analyses do not make it possible. We distinguished forms close to a regular oval, elongated oval, flattened oval, triangular, and fan-shaped.

All the advanced systems of bifacial production generate overpassed forms which are regarded as resulting from mistakes, or being outcomes not intended but ultimately accepted, or else results of intentional removal of material (see, e.g., Aubry et al. 2008; Bradley et al. 2010). We observed such forms during the analysis of the Pietraszyn 49a material. We tried to classify them based on the dorsal flake scar relief and the character of the tip part (Fig. 6).

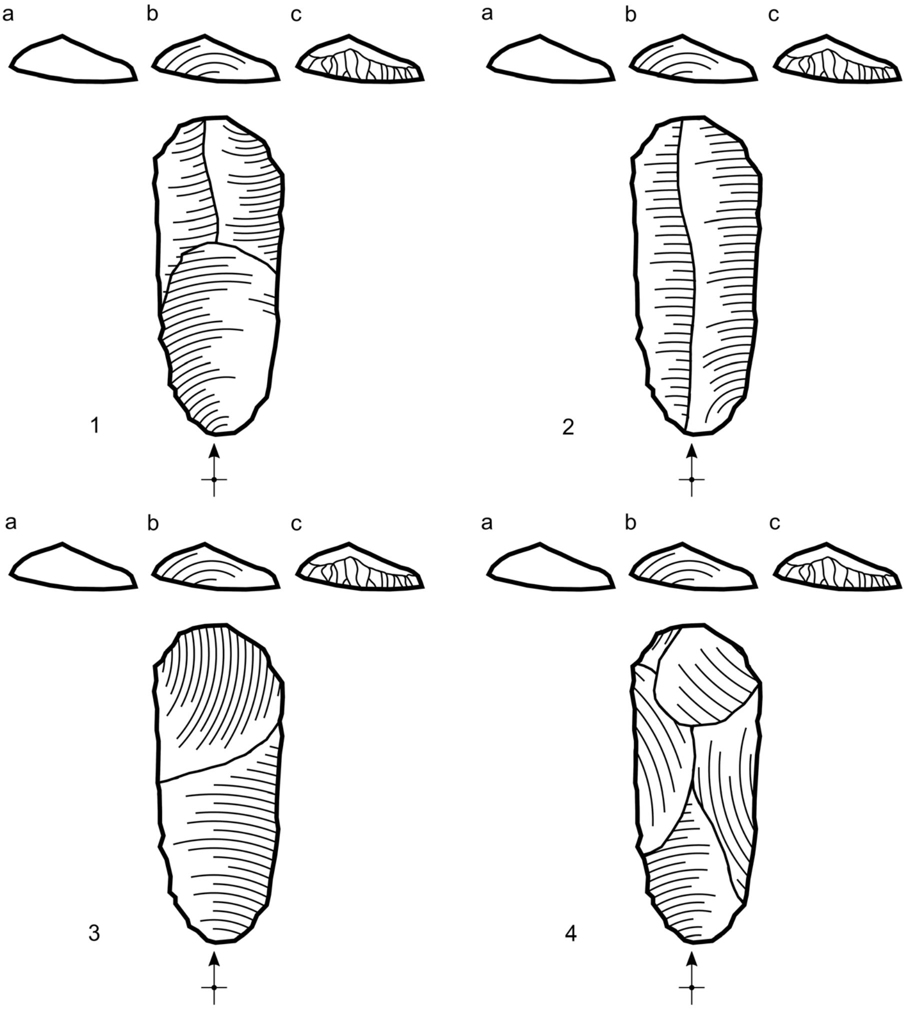


Fig. 6 Various overshot blade/flakes in terms of the pattern of dorsal face ((1) bidirectional, (2) unidirectional, (3) crossed, (4) centripetal) and characteristic of distal part ((a) raw, (b) plane, (c) facetted)

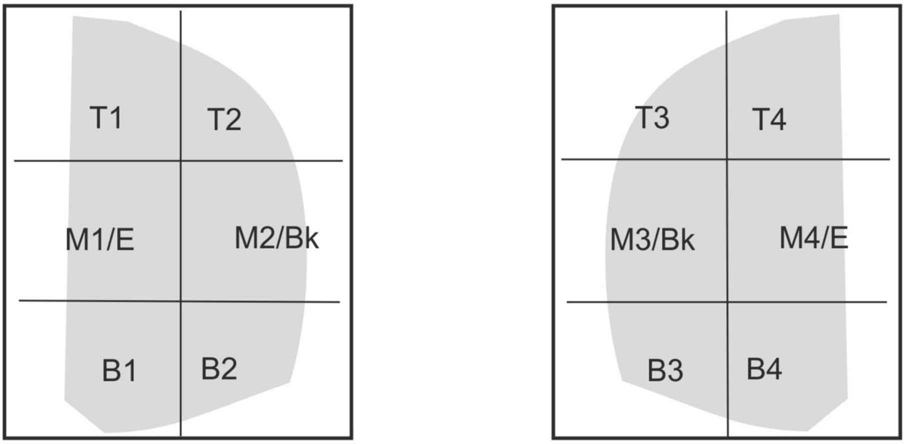
In order to ascertain which parts of bifacial tools were the most involved in reduction, we analysed the set following the protocol of McNabb et al. (2004), who used the method to characterise Acheulean handaxes. Each side was divided into 6 sectors to assess the extent of reduction on the scale of 1 (0% reduction) to 5 (100%) (Fig. 7). Unfinished tools were excluded. Besides, we analysed kinds of wear based on characteristic elements, which often formed groups of refits.

When characterising the tools, we also analysed the ways of shaping of tip and posterior parts, cutting edges, bases, and backs (Fig. 8). Except the backs, with only two varieties, in all the parts, the shape was complex, so it was possible to distinguish 5 varieties. Here we also estimated the transverse angle of the tip part and the angle of one or two cutting edges.

Morphometric Outline Analysis

As part of our analysis, we also liked to explore, if the knappers went after a desired morpho-functional shape for their bifacial backed tools. Additionally, we liked to investigate, if the outline shape morphology of the Pietraszyn 49a tools is comparable with ‘contemporaneous’ early MIS 3 bifacial backed tools from other central European assemblages.

To analyse the shape of the finished bifacial backed tools, we used an Elliptical Fourier-based outline analysis (‘EFA’) which was already applied successfully in lithic analysis (see, e.g., Archer et al. 2016; Iovita 2009, 2010; Serwatka 2015). EFA quantifies the general geometric information of the outlines, which can then be analysed using multivariate methods, like, e.g., principal component analysis (PCA)



0%	<50%	~ 50%	>50%	100%
1	2	3	4	5

Fig. 7 The division of surface of bifacial tool (both faces) into 12 sectors with the scoring of the extent of reduction (according to McNabb et al. 2004)

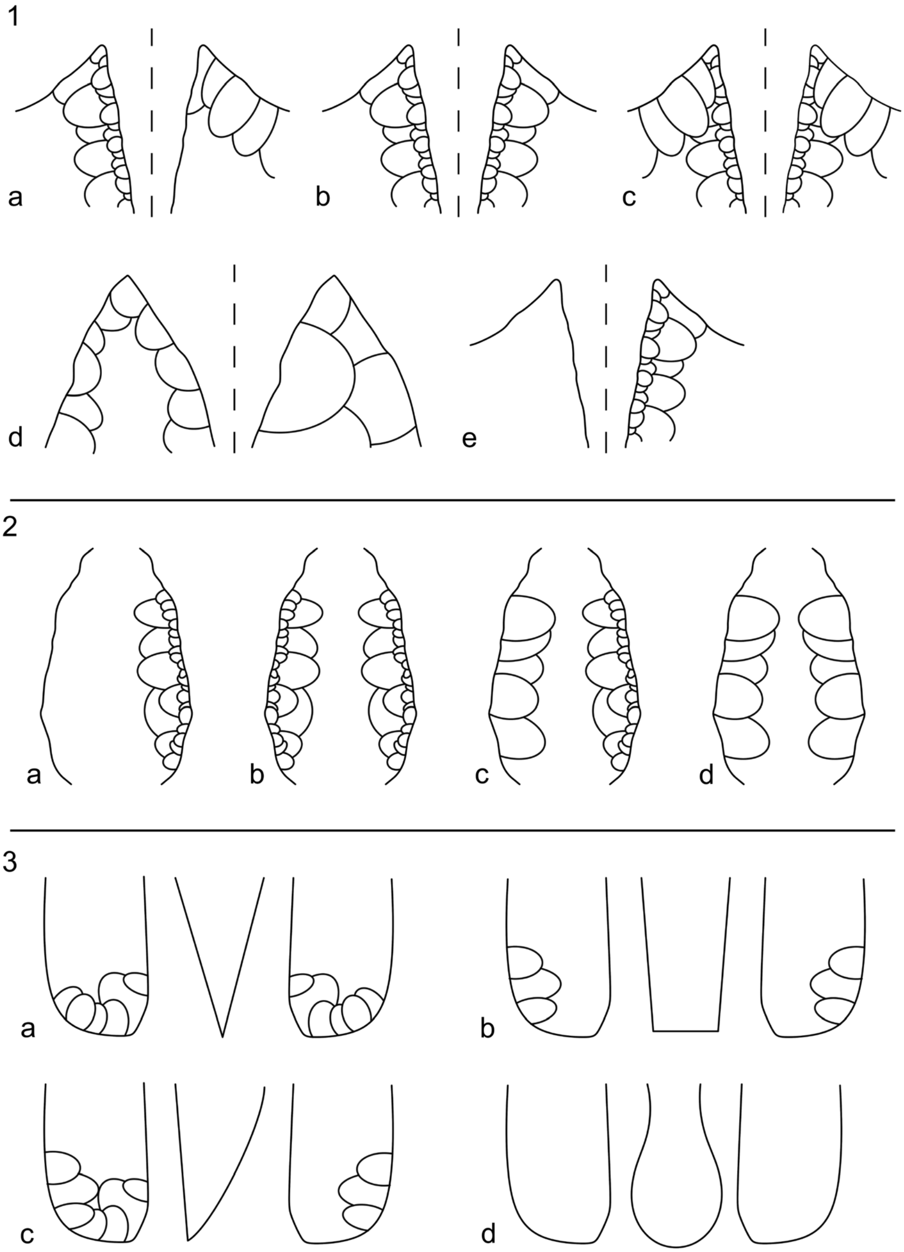


Fig. 8 Ways of shaping of tip and posterior parts (1), cutting edges (2), and bases (3)

(Hotelling 1933). Elliptical Fourier analysis decomposes closed outlines in a sum of sine and cosine curves (Bonhomme et al. 2014). These then define an ellipse in a plane. For outline shape analysis, EFA is based on the harmonic sum of these ellipses or the respective trigonometric functions, which are weighted with harmonic coefficients. The first harmonic coefficient represents the best fitting ellipse for the outlines and the other ellipses are based on this coefficient. Thereby, the harmonic coefficients cumulatively estimate a set of shapes.

The entire data management as well as the analysis was conducted in R (R Core Team 2016). Resampling of the landmarks as well as Procrustes superimposition was performed with algorithms of the packages ‘geomorph’ (Adams and Otarola-Castillo 2013), ‘sp’ (Bivand et al. 2013; Pebesma and Bivand 2005), and ‘Morpho’ (Schlager 2016). EFA was performed using the package ‘Momocs’ (Bonhomme et al. 2014).

The outlines of 23 tools from Pietraszyn 49a were analysed. The bifacial tools share common morphological features: a cutting edge, a base, and a back (Fig. 4). A fourth diagnostic feature is a sharp distal posterior part between the back and the tip. However, this feature is not always present on the Pietraszyn 49a bifacial tools and seems to be more variable. Therefore, the presence and the morphology of the distal posterior part served as a criterion for the distinction of the bifacial tools. These were divided into three groups: (1) 4 tools with no pronounced and sharp distal posterior part, (2) 13 tools with a short distal posterior part, where the distal posterior part is shorter than the back, and (3) 6 tools with a long distal posterior part, where the latter is equal in length or longer than the back.

As an exemplary case study, we compared 19 tools from Pietraszyn 49a to 16 central German bifacial backed knives, dating like Pietraszyn 49a to early MIS 3 (Weiss et al. 2018; Wiśniewski et al. 2019). The tools come from the assemblages of Pouch/Saxony-Anhalt (3), Goitzsche/Saxony-Anhalt (2), and Löbnitz/Saxony (11). The bifacial backed tools from Pietraszyn 49a with no pronounced sharp distal posterior part were excluded from this part of the analysis, as only similar tool morphologies and landmark configurations could be compared. The 2D outlines for the central German bifacial backed knives were extracted from the 3D landmark dataset presented in Weiss et al. (2018).

The landmarks from the Pietraszyn 49a tools were collected from photographs showing the objects in side view. For landmarking, we used the open-source program ImageJ 1 (Schneider et al. 2012) with the PointPicker plugin. According to the 3D analysis of bifacial backed knives presented in Weiss et al. (2018), four homologous landmarks were collected: (1) at the tip, at the intersections between (2) the cutting edge and the base, (3) the base and the back, and (4) the back and the distal posterior part (Fig. 4). For the case where no pronounced sharp distal posterior part was present, this landmark was placed at the distal end of the back close to the tip. The four homologous landmarks define four curves with 50 equidistant semi-landmarks: the cutting edge (20), the base (10), the back (10), and the distal posterior part (10). Although the algorithms of the ‘Momocs’ package includes the normalisation of the harmonic coefficients as well as making them invariant to size and rotation, the data was pre-treated using resampling and equidistant spacing of the landmarks as well as Procrustes superimposition to centre the outlines, scale the shapes to centroid size, and to orient them equally. On the one hand, orienting the shapes prior to performing EFA helped to better align the asymmetric shapes of the bifacial tools. On the other hand, the data pre-treatment was required to extract the 2D outline shapes from the 3D landmark set of the central German bifacial backed knives.

In summary, we analysed the main production stages of bifacial tools. The division of working stages was based on traits which indicated a relatively distinct change in the form of a shaped tool. These changes are a result of the involvement of particular parts of the block in the reduction strategy and the application of different shaping methods.

Thus, we considered morphological and technological attributes (see Bradley 1975) with special reference to refit groups which included tools and to tools themselves.

No doubt the shaping methods applied resulted on the one hand from the half-product morphology, on the other from the gestures and tools applied (Apel 2001, 34, 129 and others). The definition used here is closer to the concept of reduction sequence than to ascertainment of 'natural' stages according to the emic approach of some experimental archaeologists (see Shott 2003).

Results

Adaptation of Raw Material

All the objects from Pietraszyn 49a, which can be classified as bifacial backed tools, were made of erratic flint from glacial sediments of Głubczyce Plateau and the adjacent regions, such as Odra River Valley or Racibórz Basin (Kozłowski and Pawlikowski 1989; Wiśniewski et al. 2013, 2019).

The analysis of raw material adaptation revealed metric and mass differences between the artefacts grouped into classes of material modification (A to F). The data are fragmentary since we had only a few nearly complete groups of refits, but they make it possible to recognise roughly the raw material properties and directions of its modification. The changes in the average size in consecutive classes of raw material modification/reduction are smaller than the differences in mass (Table 1). It can be thus concluded that the size of the finished product, that is a bifacial tool, was of importance. The mean length, width, and thickness in classes C–E, which included preliminary and finished forms, are fairly similar, indicating than at that stage of shaping the loss of material was much smaller than in the earlier stages associated with roughing out and early thinning.

The analysis of the exposure of the tool in the natural block of raw material shows which of the external parts became parts of the tool and which underwent complete modification (Fig. 3). We analysed the exposure considering the classes of material modification. The exposure including one or two sides (A, B) was the most frequent (Table 2). This kind of exposure was present in nearly all the modification classes. The

Table 1 Classes of raw material modification and dimensional parameters

Form	Average (Length)	(Width)	(Thickness)	(Weight)	*(n)*
A	107.38	85	42.2	376.3	7
B	92.62	64.63	33.6	207.96	20
C	87.85	58.3	30.3	161.64	8
D	83.14	56.84	27.17	128	3
E	86.74	58.65	25.35	133.33	21
F	75.73	48.32	22.26	68.22	3

Table 2 Exposure of bifacial tools in comparison with classes of raw material modification

Exposure	*n*	Classification
A	12	c, d, e, f
B	11	e, d
C	5	c, e, f
D	6	d, e, f
E	28	a, b

first case (A) is probably associated with adapting flat nodules or chunks, the second (B) with adaptation of more complicated chunks and nodules which required roughing out or thinning of one part. Interestingly, the sides with natural surfaces most often form convex surfaces, while completely reduced surfaces represent flat sides of the tools. Bifacial tools resulting from complete reduction of natural surfaces are few.

It follows from the above-mentioned observations that the artisans manufacturing bifacial tools used two ways: extensive modification of raw material lumps and selection of forms that did not require much thinning.

Technique and Preparation of Striking Platform

Considering the kind of hammer used (mineral, organic), we analysed technological traces on flake platforms and on the parts of the tool surface which played the role of striking platforms. Traces were found in 33 cases, 18 of them being not completely certain (Figs. 9 and 10; Table 3). Among all the traces, 27 were to mineral hammer, 6 to organic hammer.

The use of mineral hammer is mainly associated with the stages of roughing out and thinning, and sometimes shaping. The most significant number of such traces was recorded in groups of flakes (Ptr-9, Ptr-36), and groups with a tool (Ptr-1). Traces of organic hammer occurred mainly in the series associated with thinning and shaping. Here, the majority was observed in Ptr-1 and Ptr-48.

The series of flakes document the use of only one or two kinds of hammer: mineral and organic. The latter situation was recorded in 5 cases, but in two of them, the observation is not completely certain. The observations provide no confirmation that it was always a mineral hammer which was used first and organic hammer later, as commonly accepted.

The analysis also included other traits, such as traces of edge grinding, retouching/faceting of striking platform, or the occurrence of dorsal scars resulting from the alignment of surface (Table 4). Abrasion traces observed macro- and microscopically occurred in all the analysed refit groups but not on all the flakes.

One trait seems problematic: the alignment of the 'flaking surface' before a detachment of the flake. The small number of such traces may suggest that the process was not regularly used. It cannot be excluded that such traces are associated with unsuccessful attempts of flake removal.

The faceting/retouching of the edges should be regarded as frequent. In the refit groups, it is visible that with appropriate configuration of strikes, the flake butt acquired traits close enough to *chapeau de gendarme*. The observations show that the faceting could take place both at the stage of thinning and of shaping.

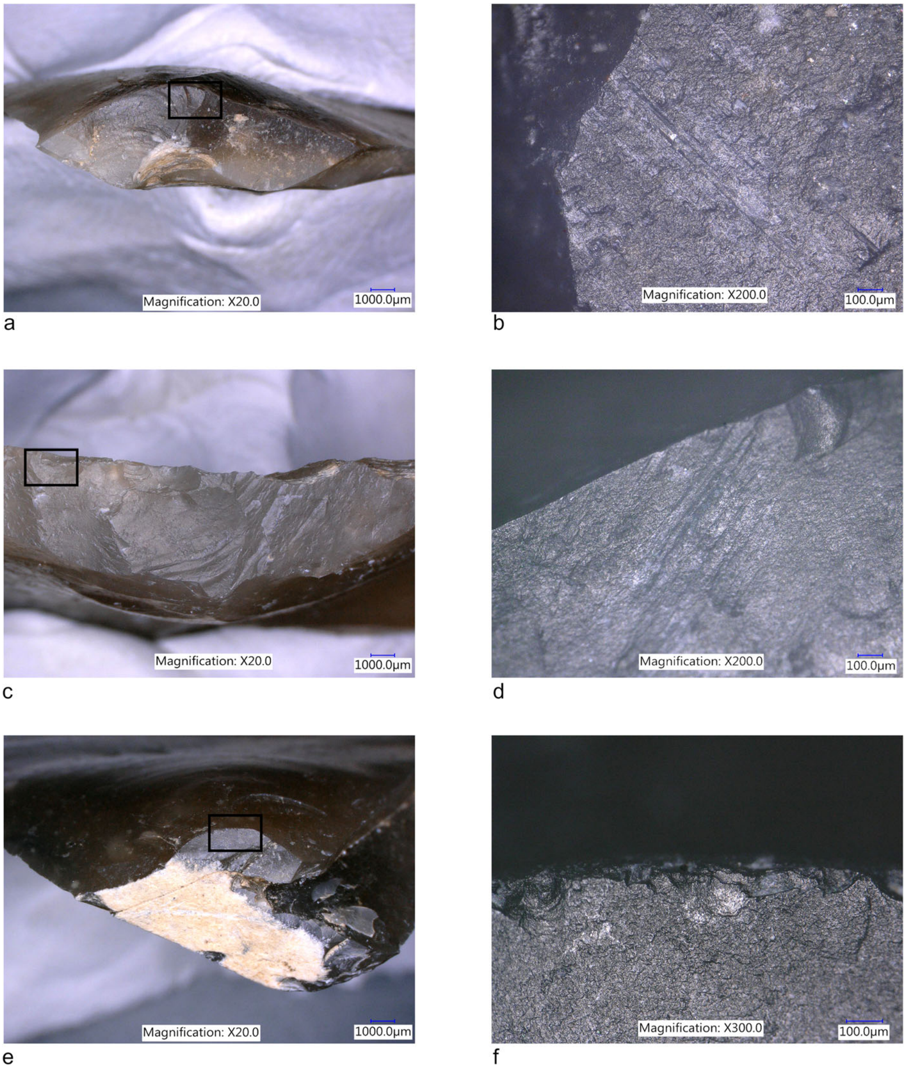


Fig. 9 Technological traces. (a) Flake butt (ARTCL584) with the marked place of occurrence of traces. (b) Traces showing use of stone hammer. (c) Flake butt (ART1789) with the marked place of occurrence of traces. (d) Technological microscopic traces illustrating abrasion of the flake butt ridge using stone tool. (e) Flake butt (ART551) with the marked place of occurrence of traces. (f) Technological microscopic traces showing flake's detachment (ARTCL584) with organic hammer (antler?)

We also considered the possibility of the isolation of striking points by the removal of some chips. The analysis of the refit groups revealed only a few such cases (6 objects). They occurred individually, mainly on flakes with their platforms facetted in a way aimed at producing an adequately protruding part of the margin. It can be assumed that despite their small representation in the refit groups, faceting was intentional. It is known from other CEEM sites, for example the eastern part of the complex (Richter 2004, 235; see also Andrefsky 1994; Tomka 1989, 147; Shott 1994, 80).

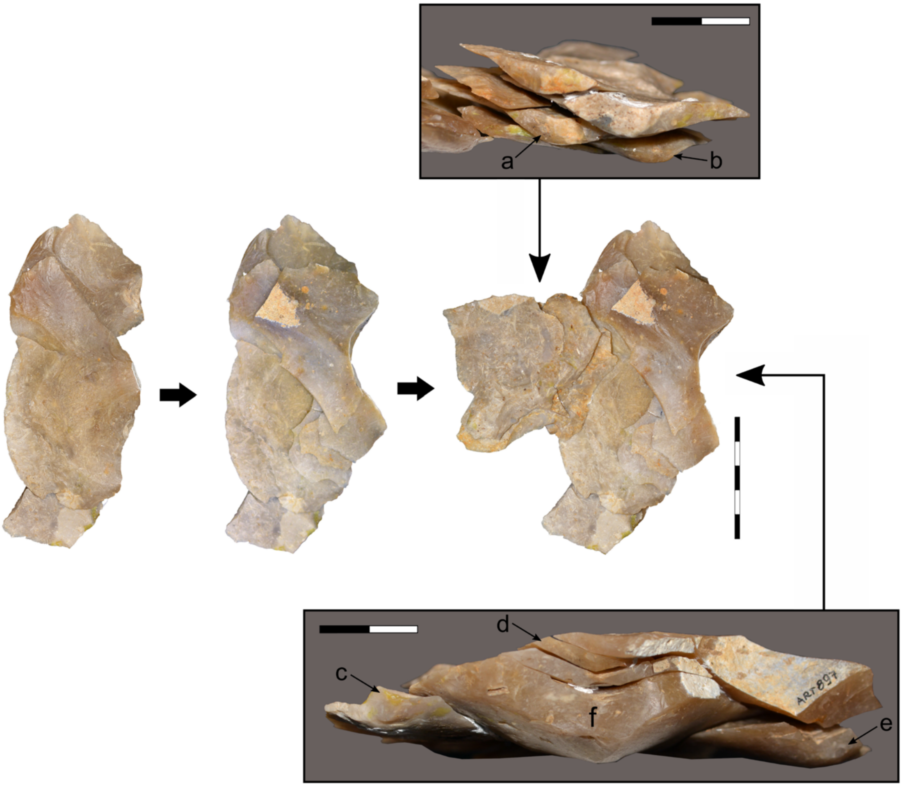


Fig. 10 Steps of refitting of flake group (Ptr-9) and location of flakes which were detached with various hammers. (a) Mineral hammer? (detachment of flake). (b)–(d) Mineral hammer (detachment of flake). (e) Mineral hammer (detachment of flake, grinding). (f) Organic hammer/antler? (detachment of flake)

For the analysis of the detachment angle, we selected the exterior platform angle (see remarks Cochrane 2003). The angle ranges from 56° to 98°. In the flakes removed from plane surfaces, the mean angle was 81° ($n = 60$), for convex surfaces it was 78° ($n = 7$).

Table 3 Technique of flake detachment that was recorded within groups of refits

Group of refits	Mineral	Organic	No hammers	Stage
Ptr-36	3	0	1	Thinning
Ptr-18	2	1?	2	Roughing out/thinning
Ptr-9	4, 1?	1?	2	Thinning/shaping
Ptr-20	1	0	1	Thinning
Ptr-2	1, 1?		1	Roughing out/thinning/shaping
Ptr-96	3, 1?	1	2	Thinning
Ptr-10	1		1	Thinning
Ptr-86.1	2?	3?	2	Thinning/shaping
Ptr-1	2, 1?	1, 4?	2	Thinning/shaping
Ptr-48	0	1, 3?	1	Thinning/shaping

Table 4 Technological features regarding flake detachment

Group of refit	Grinding	Retouching/faceting	Dorsal scar	Isolation of point
Ptr-36	2, 1?	7, 4	4	2?
Ptr-18	2	1?, 3	1?	
Ptr-9	3	2, 5	3?	1?
Ptr-20	1, 1?	1 i 1?	1	
Ptr-2	1	3	1?	
Ptr-96	1	2, 1	1	
Ptr-10	1	1, 1		1?
Ptr-86.1	1	1, 1		
Ptr-1	2, 2?	6, 11	3?, 1	2?
Ptr-48	1?	1, 1?	1, 1?	
	19	53	17	

There is no significant difference in the angle between the two sides (*t* test: $p = 0.35$), though forms of flakes detached from plane and convex surfaces are often interpreted to be different (see, e.g., Demidenko 2015). The angle formed during the shaping of plane surfaces is very close to the angle of preparation of levalloisian cores (see Van Peer 1992 and others). In our opinion, it is not an accidental similarity, but a result of skill in detaching the flattening flakes parallel to the plane which hierarchizes the tool.

Selected Traits of Thinning and Shaping

It is commonly accepted that the flat and convex sides of tools were formed using different strikes which was reflected in a slightly different relief of the two sides/surfaces (Gouédo 2001; Jöris 2001; Iovita 2014; Richter 2004). We tried to obtain a more precise information by analysing the proportion of scars on the plane and convex surfaces. The proportion of various kinds of scars shows that scars involving the whole surface or those associated with overpassed flakes occur mainly on flat sides, while the

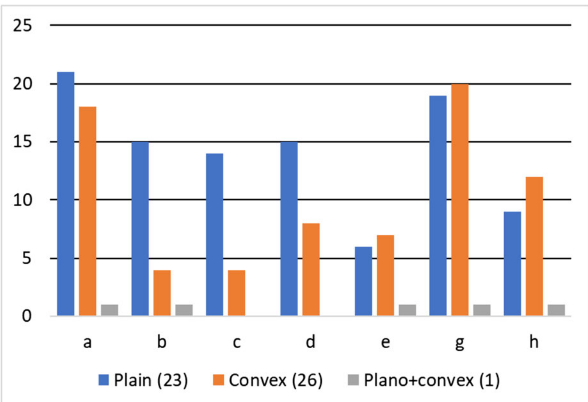


Fig. 11 Number of various types of flaking (a–h) on plane, convex, and plano-convex face

Table 5 Types of flake scars. "Comedial" flaking (f) was excluded

Face	a	b	c	d	e	g	h
Plane (23)	21	15	14	15	6	19	9
Convex (26)	18	4	4	8	7	20	12
Plano+convex (1)	1	1	0	0	1	1	1

remaining kinds occur on both sides (Fig. 11; Table 5). Scars of type a, i.e. overlapping, also occur very often on flat sides. Flakes detached from tips or striking platforms (e) are infrequent.

The scars reflect the different ways of organizing the two surfaces. The plane surface required removal of a larger quantity of material; hence, the scar surface area is much greater than on the convex surfaces. They usually have a different outline. Scars on the plane surface of finished tools, categories a–c, vary considerably depending on the size of the processed block, the processed part of the future tool, and technical problems.

In terms of scar outline, the prevailing shapes are oval (1), slightly elongated (2), or flattened oval (8). Fan-shaped forms are also present (6), while the remaining ones, for example triangular, are much less frequent. In the case of refits, plane surfaces most often bear also scars of types 1 and 2.

The flakes from upper or convex surfaces not related to the ultimate configuration have less variable outlines, type 1 forms predominating. The convex surfaces often generated flakes of bending type with a characteristic curvature (see Cotterell and Kamminga 1987). Manufacturing of forms with straight cross-sections is also known from refits.

Overshot Forms

We think that a part of the overshot forms from Pietraszyn 49a is intentional. Among larger flakes/blades of 3 cm in length and longer, we selected 30 forms (see Figs. 6 and 12). Some formed refits (Art15232). Most of the forms result from unidirectional reduction (2) or bidirectional reduction (1), while those showing evidence of multidirectional or perpendicular reduction suggesting a radical change in the concept of shaping are rare. The overshot forms in the groups of refits suggest thinning of their basal (Art15232) or middle parts (Ptr-48). The location of some of them suggests that they were routinely detached; some of them resemble debordant flakes.

The Formation of the Morphological Parts of Bifacial Backed Tools

Below we characterise the way of the formation of strategic/morphological parts of bifacial backed tools based on specimens representing the whole range of the processing procedures. The arrangement of scars of the tip part (5 patterns) shows that most resulted from a series of strikes which ran perpendicularly to the cutting edge on one or both sides; only subsequently elongated flakes were detached perpendicularly to the tip edge and posterior part. The mean angle between the ventral and dorsal sides in the tip part was 31° ($n = 18$, 69%; range 21–70°).

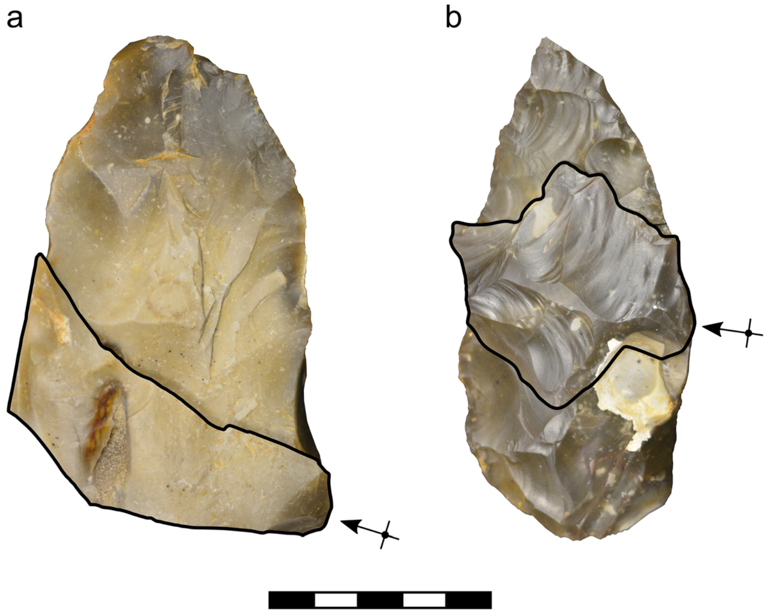


Fig. 12 Examples of overshot flakes/blades (the group of refits: Ptr-48 and Ptr-99)

The analysis of the cutting edge of bifacial tools indicates that it most often was made using a series of strikes during configuration, in most cases on the dorsal side, less often using bifacial reduction. The mean angle of the right edge was 46° ($n = 26$, 100%), of the left one 46° ($n = 6$, 23%). The values ranged from 30° to 80°.

Regarding the base of the tool, probably there existed no general concept. In general, it can be observed that the base was isolated in such a way that minimised the effort required by its reduction in later stages. This is the reason for the small frequency of complex processing which would include both sides.

One of the distinctive traits of the analysed tools is the presence of back. We distinguished two varieties: (1) Natural surface (cortical or another natural surface (chunk) present on the back, no traces of preparation, in its tip part the back passes into posterior part;(2) the back bear scars demonstrating unidirectional strikes, sometimes the back passes into posterior part. Interestingly, variety 2 is represented by single tools. Overall, forms with natural back, with no signs of configuration, predominate (15 specimens).

Range of Reduction

The analysis of the reduction range shows that the most involved parts were the tip part and upper fragments of the cutting edge and the distal posterior part. Less frequent was the evidence for reducing the middle part of cutting edge (Fig. 13). The proportion in the case of the base and back was small or negligible. The observations provide the answer to the question which techno-functional units required shaping, and which were free from shaping.

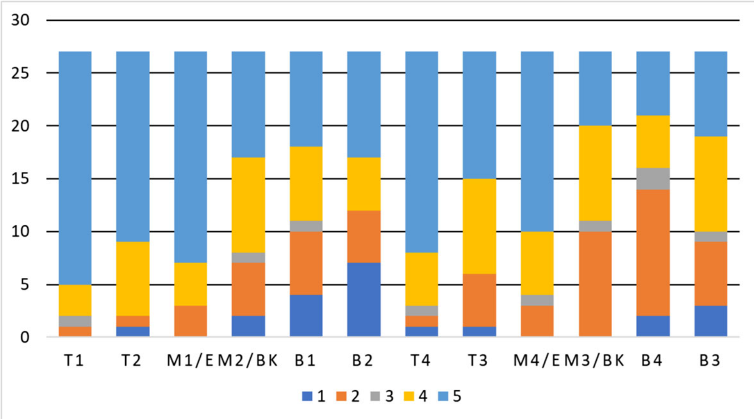


Fig. 13 The extent of reduction in the sectors (T, M, B) of bifacial tools

Tool Damage

We assessed tool damage to ascertain which parts were most often damaged and what were the consequences of such accidents (see Fig. 4). The observations were based on a rather small sample ($n = 32$). Despite this, it can be noticed that nearly 68% are fragments of tip parts (Fig. 14). It was the most frequent damage. Mostly the damage occurred in the middle or advanced stages of manufacturing and was mainly associated with shaping the thinnest parts of the tool. In some cases, as demonstrated by the refit group Ptr-48, the damage resulted in abandoning the tool; in others, as in the case of group Ptr-1, production was resumed using one of the preserved fragments.

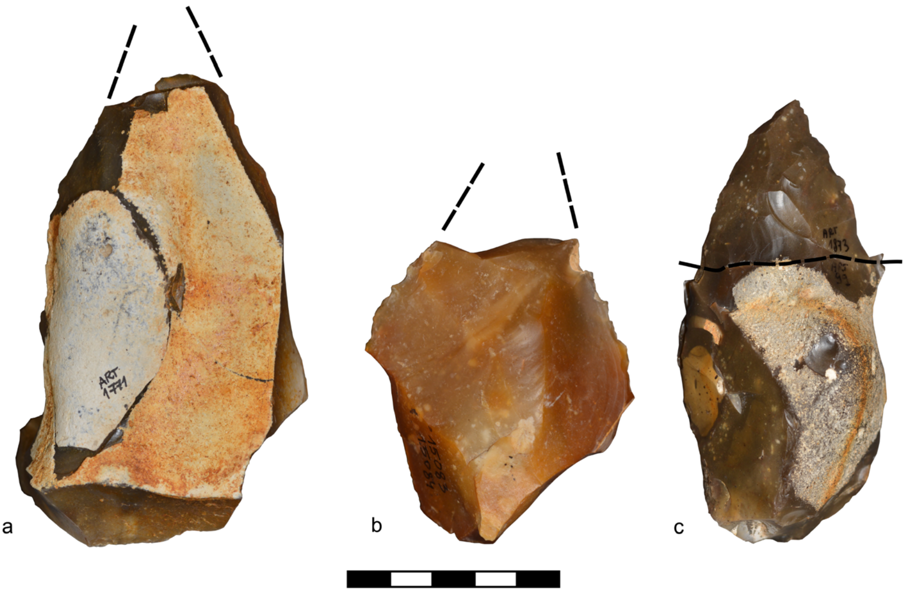


Fig. 14 Tools in a different stage of shaping with damages of the tip parts

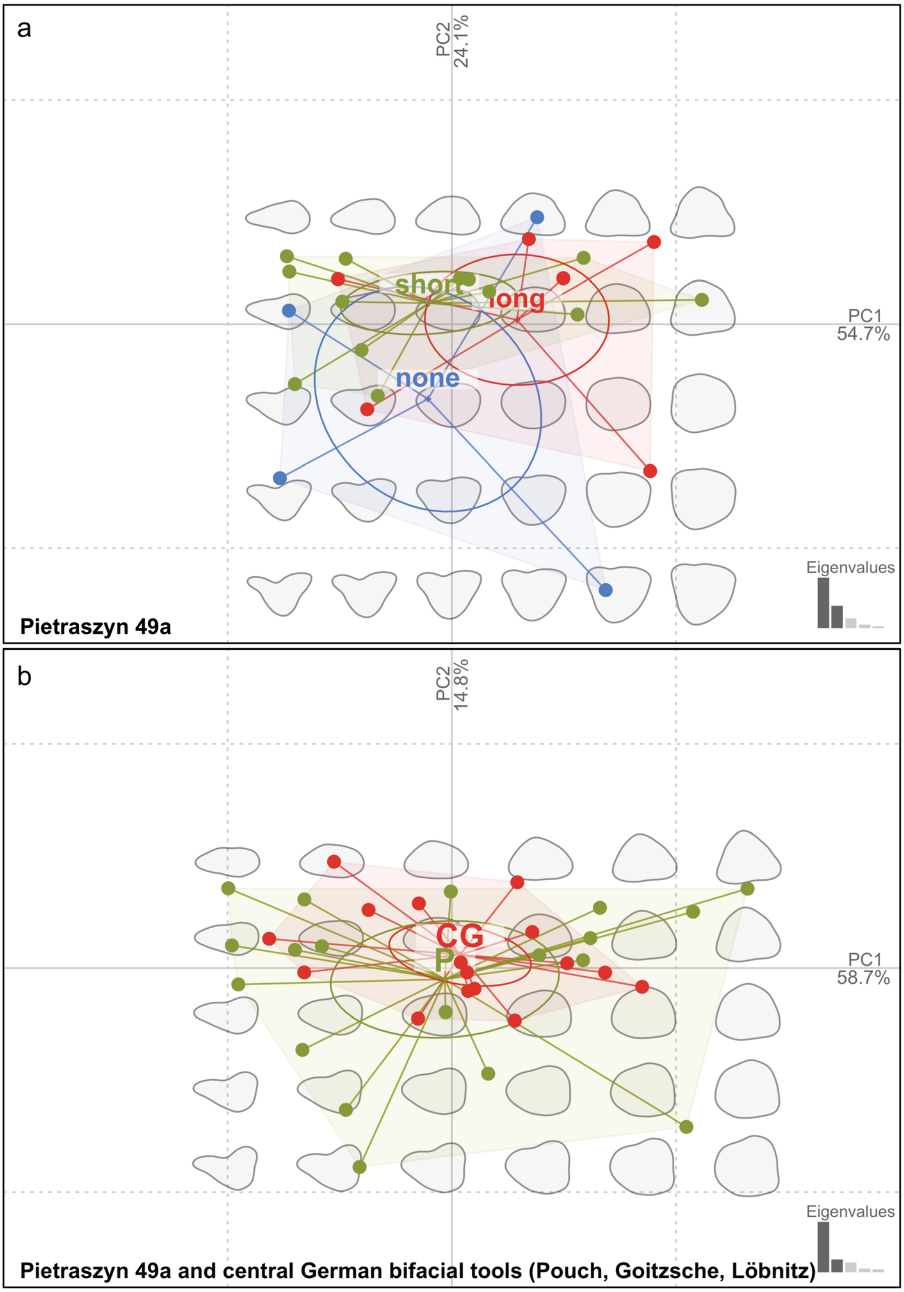


Fig. 15 Factorial maps depicting the morphological variation of bifacial backed tools from (a) Pietraszyn 49a and (b) from Pietraszyn 49a and central Germany (Pouch, Löbnitz, Goitzsche, see Weiss et al. 2018). (a) Displayed are the two main principal components of the first 10 harmonic coefficients of tool shape of the 3 groups defined by the presence and extension of a sharp and pronounced distal posterior part. (b) Two main principal components of the first 10 harmonic coefficients of tool shape of Pietraszyn 49a and the central German assemblages of Pouch, Löbnitz, and Goitzsche. Excluded are the 4 pieces from Pietraszyn 49a with no sharp and pronounced distal posterior part. Both figures display additionally the eigenvalues, the spatial centre of each group, the 95% confident ellipses, and the morphological space. Within the latter, the cutting edges of the shapes point down left

Elliptical Fourier-Based Outline Analysis

Figure 15 shows the results of the EFA in the form of factorial maps depicting the morphological variation of bifacial backed tool shape based on the two main principal components of the first 10 harmonic coefficients. That 10 harmonics are sufficient to reconstruct and explain the tool shapes is evidenced by the cumulative sum of harmonic power (Fig. 16): five harmonics already explain 95% and ten harmonics 99.9% of shape variability.

The EFA result for the bifacial backed tools from Pietraszyn 49a (Fig. 15 a) indicates that tools with a long and a short distal posterior part are relatively similar in shape to each other. In contrast, the group centre of the tools bearing no pronounced and sharp distal posterior part is slightly separated from the other two groups. These bifacial backed tools show also a higher range of outline shape variability. Despite the overlap with the other two groups, two specimens without a distal posterior part are completely out of the range of tools with a pronounced and sharp distal posterior part. However, the mean shapes (Fig. 16) suggest that the knappers followed a general morphological tool concept. Thereby, the convex cutting edges and the tip areas seem to be rather standardised. What varies the most are the shapes of the bases and the backs. This is potentially the result of the incorporation of natural

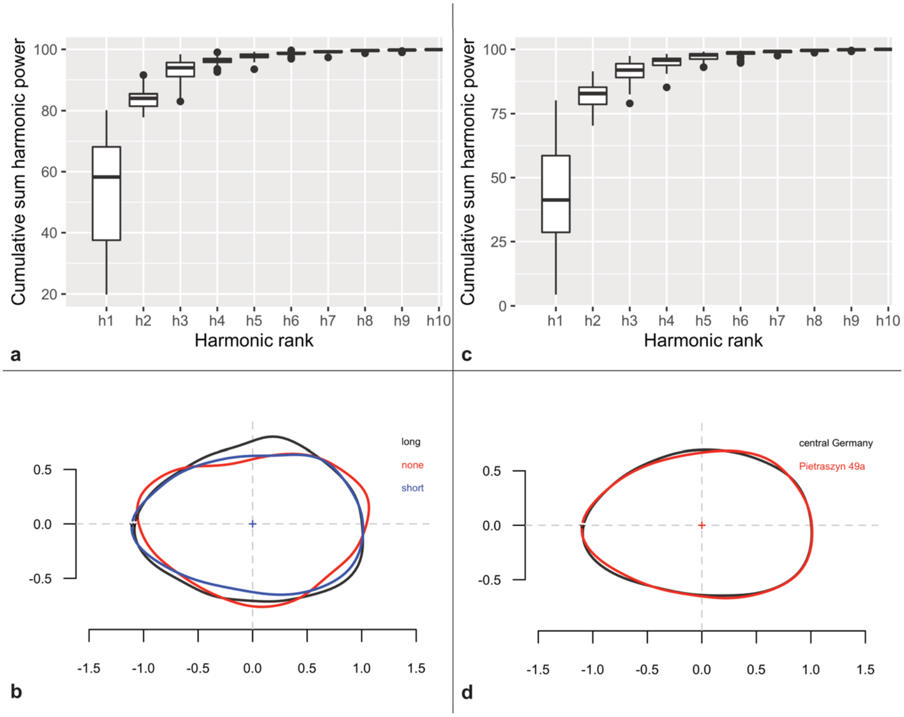


Fig. 16 The cumulative sum of the harmonic power and the mean shapes of the EFA displayed in Fig. 15. (a) – (b) Pietraszyn 49a, (c) – (d) Pietraszyn 49a and central Germany. (a) and (c) Plot of the cumulative harmonic power of ten harmonic coefficients. The values of the boxplot display the cumulative harmonic power of each coefficient on each single specimen. The first 4 coefficients account for 90%, the first 5 for 95%, 8 harmonic coefficients for 99%, and 10 coefficients for 99.9% of shape variability. (b) and (d) Diagramms of the mean shapes for the individual groups. The cutting edges point down left

nodule parts as backs and/or bases, which show a rather high shape variability (see also the shapes displayed in the morphological space of Fig. 15). An additional pairwise MANOVA on the principal component scores reveals also no significant difference between the three groups: (1) long – none: Pillai = 0.7067, approx. $F = 3.0111$, $p = 0.1289$; (2) long – short: Pillai = 0.3504, approx. $F = 1.8876$, $p = 0.1686$; and (3) none – short: Pillai = 0.2458, approx. $F = 0.9777$, $p = 0.4555$. However, this test result should be regarded with caution, as the group 'none' has only 4 specimens which lead to low degree of freedom values of 4 for all tested relationships.

The comparison to the central German bifacial backed tools from the assemblages of Pouch, Goitzsche, and Löbnitz (Fig. 15 b) revealed that the latter and Pietraszyn 49a are overlapping, and the position of the group centres differs only slightly from each other. This obvious similarity is reinforced by the result of a MANOVA on the principal component scores, which shows no significant difference between the two groups: Pillai = 0.888, approx. $F = 0.499$, Df = 32, $p = 0.848$. Additionally, the mean shapes of the tools from both geographical areas displayed in Fig. 16 are almost identical. Thereby, the knappers of both regions focussed on the creation of convex cutting edges. This was also reported for the likewise to early MIS 3 dated bifacial backed knives from Lichtenberg (Lower Saxony, Germany) (Veil et al. 1994). However, despite the overlap of the two groups, the central German bifacial backed tools show a tighter range of shape variability than the bifacial backed knives from Pietraszyn 49a.

Summary: the Stages of Manufacturing Bifacial Backed Knives

Analysis of the refit groups as well as various waste and finished tools from Pietraszyn 49a made it possible to reconstruct a few stages of manufacturing of bifacial backed tools (see Fig. 17):

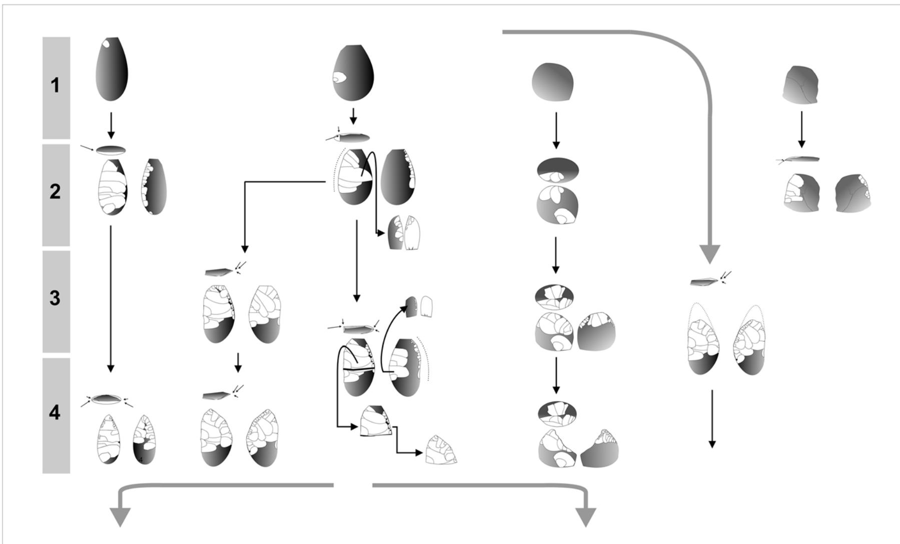


Fig. 17 Schema of operational sequences concerning the transformation of lithic raw material at Pietraszyn 49a. Most of parts of model were reconstructed on the base of groups of refits. The numbers from the left refer to manufacturing stages. Detailed description in Chapter 3.9

A *Procurement of blank pieces of raw material and testing*. This stage is represented by objects which showed no or only single isolated scars (type a1–a3): cobbles, nodules, and chunks. Mostly the specimens do not indicate the intended way of reduction of the block.

B *The early stage of production*. This stage shows traces of a series of strikes on one or both sides, i.e. one side played the part of a striking platform (type b1–b2). In this stage, various flakes were removed, including forms with a large surface area covered with natural surfaces, often passing onto the other side. It can be compared with the rough-out stage when a decision was made regarding the tool exposure in the block of raw material. The initiation of the reduction depended on the shape of the raw material: 1. In the case of flat and elongated pieces, the reduction started at the elongated sides (Ptr-48); 2. In the case of more spherical forms, the reduction most often started from the poles, and then proceeded along one of the sides (Ptr-96, Ptr-86). This stage provided preforms for further processing which already showed the planned direction of one-sided or two-sided thinning.

C *The middle stage of production*. The stage resulted in the hierarchization of the sides through intensive thinning, followed by the establishment of the main morpho-functional elements like the tip, the cutting edges, and the base with the back (types c and d). The resulting plano-convex forms are rather massive in their tip and middle part. The stage resembles the strategy, described by Boëda (1991) in the context of a trifacial approach. It involves a whole range of techniques. The removal of flakes from the flat and convex sides was controlled and may be two-directional or take a centripetal direction. The stage generated numerous mistakes which led to the discrad of the tool or to a change of the production concept. This stage resulted in the formation of the most numerous and technically varied waste in the form of flakes, but as a rule, the flakes separated from the main surface did not have marginal character.

D *The late stage of production*. In this stage, shaping was sometimes continued, but the processing was mainly aimed at subapical parts of the surface and the contour of the tip and the cutting edge (type e). The length of negatives resulting from edge configuration usually does not exceed 10 mm. The edge retouch involved only parts of the tool and was oriented towards the dorsal, convex side. The stage generated very fine waste. Though the stage is documented at the site, it is represented by the smallest number of refits because of technical problems and the time-consuming character of reconstruction.

Discussion

Our studies indicate that the manufacture of CEEM bifacial backed tools was structurally complex. The most representative refit groups made it possible to distinguish as many as 4 stages: from testing through thinning and shaping to the regularisation of the active parts of the tool (Fig. 17). The varied character of the raw material caused the omission of some stages, or that some stages required a smaller or, conversely, greater input of work. Additionally, the EFA result has shown that especially the morphology of the back resulting also from the varied character of the raw material led to main shape difference of the finished tools.

The complex scheme of production was subordinated to the concept of geometric hierarchization which can be regarded as pre-adaptation or a kind of template. Geometric hierarchization, as shown by the analyses of the relief and the shape of scars, as well as waste morphology aimed at achieving plano-convex cross-sections. Maintaining a plane that should be prepared in the first two stages was crucial, but as a rule, the final shape was achieved as late as the third stage. This surface was only rarely subject to modification in the last stage. Except the closest vicinity of the cutting edge, it was not re-modified.

The flat surface was achieved by removals parallel to the biface plane. Plane cross-section could be maintained only through removal of flakes crossing the tool axis (Gouédo 2001) or flakes which contacted in the middle part. In our opinion, overshot flakes were important. The examples show that they arose during the removal of obstacles in the form of hinges and steps on the surface, but they may have been formed during the removal of marginal convexities, becoming similar to marginal forms. We did not find that their removal led to the correction of opposite platform, as was confirmed for later bifacial systems (Aubry et al. 2008; Bradley et al. 2010).

A whole range of techniques was employed during the preparation of the plane and convex surfaces of the bifacial backed tools, including several varieties of retouch and also edge abrasion. Some of them were already noticeable in Middle Palaeolithic industries of Western Europe. The rather small number of observations of such modifications results from the fact that the state of preservation of many inventories precludes their analysis. Additionally, technological knapping traces are often on the third place in the order of microscopic analysis, often being preceded by the analysis of wear traces and hafting traces (Rots 2015; Soressi and Hays 2003). These procedures were better defined in the context of advanced bifacial system of the Late Palaeolithic (Bradley et al. 2010; Callahan 1996).

Our microscopic analyses show the application of various tools: 1. mineral hammers, 2. organic hammers, or 3. a combination of the two. In the analysed refit groups, we have evidence that traces of organic hammers are many times less frequent than those of mineral hammers. This does not have to be tantamount to the prevalence of mineral hammers. Actually, organic hammers may have been used more often, but traces left by organic material on the surface of flake platforms or on the tool surface are not easy to identify. Nevertheless, the data may indicate either the diversification or the use of the two techniques as complementary.

The complex scheme of production was also subordinated to the concept of specifying active and passive elements of tools, i.e. morpho-functional units—prehensile, transmitting, and active volume (Boëda 2013). Their specification required first of all a plan which would consider the morphology of the half-product (nodule, chunk, or flake) and thus optimise the selection of the corresponding parts. Active parts required a greater work input and generated the greatest number of surface damages (e.g. hinges) or fractures.

Passive parts, such as the base or the back, were rarely subject to major modifications. Interestingly, apart from single forms, there are no traces of special preparation of the back as the potential striking platform for separation of flakes during thinning or shaping. It appears that the limited processing or its lack is associated with the possibility of earlier inclusion of the back in the plan of the future bifacial tool.

Our results throw light on the dynamics of consecutive production stages. Forms produced with a small work input alternate with forms which, because of shapeless raw material or unexpected events during processing, were subject to relatively long reduction. The latter case generated a greater number of various-sized waste compared with easily modified specimens. This suggests a limited value of assessment of the degree of tool reduction without confrontation with the initial stage of manufacturing. In other words, the Frison effect (1968) in the context of Micoquian bifacial tools (for allometric or isometric changes: see Iovita 2010) may result from both repeated sharpening and re-modifications during the production in the workshop.

It is also noteworthy that in many cases the cutting edge of the tool was modified through a series of removals only from the dorsal side, with no attempt at thinning the flat side. It should be emphasised that despite the rather large angle of the cutting edge (mean ca. 46°), no additional modifying procedures were used in Pietraszyn 49a, for example tranchet blows (see Frick et al. 2017). It should be borne in mind that the average values of the cutting edge angle in Pietraszyn 49a are close to those from other sites in which no Pradnikian elements (i.e. tranchet blows) were recorded (Weiss et al. 2018). Metric characters of the angle result from the specific configuration of the edge which in Pietraszyn 49a consisted mainly in removal of a series of invasive flakes perpendicularly to the cutting edge. Interestingly, the tip part of the tool was formed more precisely. The strikes were directed perpendicularly to the distal posterior part, or obliquely but convergently, attaining a much thinner cross-section and thus a sharp distal posterior part. On the whole, the structure of some of the tools from Pietraszyn 49a resembles the scheme used in the cave site Bockstein Schmiede (Bavaria, Germany) (Çep 2014).

It can be speculated that the separation of the two elements may have been associated with their different functions: for example, tip—piercing and stabbing, edge—cutting, scraping, whittling, etc. (Jöris 2006; Frick et al. 2017).

Our analysis of the outline shapes of the bifacial backed tools from Pietraszyn 49 revealed a certain range of internal variability of the finished tool forms. However, this seems mainly due to the incorporation of natural backs variable in shape into the tool concept. In contrast, morpho-functional active parts like the convex working edge and the tip area seem rather standardised in shape. However, obtaining an accurate answer to the question of how much both parts were subject to standardisation requires separate morphometric studies. Variation in overall shape can also be due to the different state of the reduction of the bifacial backed tools (Jöris 2001, 2004, 2006, 2012; Migal and Urbanowski 2006; Urbanowski 2003), while the configuration of the morpho-functional parts was retained during the reduction process (Iovita 2010). The exemplary comparison with 'contemporaneous' bifacial backed tools from central Germany revealed an intriguing morphological similarity between the tools from both regions. Noteworthy is the focus on convex cutting edges which we can also observe at the MIS 3 site Lichtenberg (Veil et al. 1994). Despite a larger internal shape variability of the Pietraszyn 49a tools compared with those from central Germany, we think it is justified to infer that MIS 3 Neanderthals used the same tool concepts in both regions of the central European Plain. Therefore, we can infer that the production system of bifacial backed tools applied in Pietraszyn 49a may also be valid for ‘contemporaneous’ CEEM bifacial backed knives from other regions in central Europe.

No doubt, the Micoquian bifacial system, documented in Pietraszyn 49a and other sites, includes an array of technical solutions which were present already in the Acheulean, or in the industries of Mousterian of Acheulean Tradition of Western Europe of the same age (Hallos 2005; Soressi 2004; Soressi and Hays 2003). At the same time, it can be said that later industries of the early Upper Palaeolithic, for example the Szeletian, also used some procedures known from the CEEM bifacial system. These would include involvement of the back/striking platform in thinning/shaping. It should be noted that it was only the stage of shaping that aimed at biconvex character of the blade (for reconstruction see Nerudová and Neruda 2017, Fig. 8; Mester 2018). It should also be pointed out that flat-convex tools were also found in some sites regarded as Szeletian; the two Polish sites are located in the same region as Pietraszyn – Głubczyce Plateau, i.e. Dzierżysław 1 and Lubotyń 11 (Fajer et al. 2004; Poltowicz-Bobak et al. 2013; see also Škrdla 2013). Unfortunately, the present state of research of the two inventories does not make it possible to decide if the forms were primary products or re-modified tools. Besides, at Dzierżysław 1, due to the complicated stratigraphic situation, the presence of an older admixture in the inventory, i.e. Micoquian, cannot be excluded. The comparison of the way of tool shaping/thinning in Pietraszyn 49a and the above-mentioned Szeletian sites does not provide a basis for suspecting that technology is a medium of endemic development of the CEEM into the Szeletian (Oliva 1995; Valoch 1990). Such a scenario is, however, supported by non-technological arguments: harmonious passage of late Micoquian dates into those of Szeletian sites, as well as the overlap of geographic distribution of sites representing both units in Poland, the Czech Republic, Slovakia, Hungary and Ukraine (Kaminská 2015; Kozłowski 2017; Mester 2018; Neruda and Nerudová 2013). Since the data are still rather tentative, also other scenarios are relevant to the discussion, for example interaction between the Micoquian and other cultural units (see Tostevin 2007; Greenbaum et al. 2019).

Conclusion

The technological and morphological analysis of the material from the bifacial tool workshop in Pietraszyn 49a, mainly based on refit groups and finished tools, leads to a few conclusions. Some of them confirm the existing views, the others modify and supplement the existing knowledge.

First of all, it appears that in the CEEM, irrespective of the raw material standards, the manufacturing of bifacial backed tools followed a structural scheme with a fluid division into stages. Not all the stages necessarily involved a different technique, i.e. a different hammer, but each mostly involved a slightly different way of shaping of the tool. The production dynamics could be diversified enough to make some of the manufacture of the tool in the workshop resemble forms resulting from re-modification. A major part in the tool production was played by the original material, but in the case of Pietraszyn 49a, it cannot be said that it determined the final form of the tool.

On the contrary, the production in Pietraszyn 49a appears to have been governed by some pre-defined principles, one of them being following a hierarchical model of the shape of the tool which had to include a plane and a convex surface. In spite of this, tools of other shapes (e.g. biconvex) were found. The production was definitely aimed at distinction of active parts (tip and cutting edge), with little work invested into the base and posterior part. Thereby, the bifacial backed tools from Pietraszyn 49a followed similar 'contemporaneuos' morpho-functional shape concepts as in other regions of central Europe, in our example central Germany. Some techniques employed during the shaping (detaching overshot flakes) resembled later techniques of producing bifacial tools.

The effect of Micoquian technology on the development of some EUP industries is still unanswered. The hitherto attempts at finding technological similarities brought no confirmation. Technologies, for example Szeletian, provide evidence of procedures otherwise found in the production of Micoquian tools. It should be remembered, however, that in the Szeletian, such procedures are only links in a longer chain of operations and not its last stages, as opposed to the Micoquian.

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