SHAPE VARIATION OF MIDDLE PALAEOLITHIC BIFACIAL TOOLS FROM SOUTHERN POLAND: A GEOMETRIC MORPHOMETRIC APPROACH TO KEILMESSERGRUPPEN HANDAXES AND BACKED KNIVES

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ABSTRACT

In the past decade, geometric morphometrics have come to be widely implemented in lithic studies. Because of the application of multivariate statistical methods, morphometric shape analysis is considered an accurate methodological tool for exploring the diversity of bifacial artefact morphology. The aim of this paper is to test the utility of morphometric outline shape analysis in assessing the variability of Late Middle Palaeolithic (LMP) bifacial artefacts. An assemblage of 42 handaxes and 51 Keilmesser was analysed and compared to 54 LMP leaf points to seek out patterns of their shape variation. The results reveal patterned changes of bifaces’ proportions that may have been caused by continuous reduction, as well as by diachronic changes in artefact design.


Keywords: Late Middle Palaeolithic, Keilmessergruppen, geometric morphometrics, Keilmesser, handaxes, leaf points

INTRODUCTION

Classification of bifacial artefacts has always been a problematic issue in lithic studies. Given the numerous factors influencing the morpho-technological features of bifaces, such as raw material properties, reduction and resharpening trajectories or knapping skills of ancient artisans (e.g. Kelly 1988; Pope et al. 2006; Stapert 2007; Machin 2009; Archer & Brown 2010), it is often hard to properly interpret the diversity of their forms.

Particular difficulties in the subject of bifacial artefacts classification can be observed in central European studies on Keilmessergruppen implements (Hauser 1916; Bosinski 1967; Sobczyk 1975; Richter 2000 & 2002; Ruebens 2006). Given the strong inclination towards the manufacture of bifacial tools, it is often hard to distinguish artefact types, since one form merges into another. In traditional typology, one of the criteria taken into account during classification is the overall shape of an artefact with respect to handaxes (Bordes 1961: 80–85) or the outlines of individual tool’s sections in case of Keilmesser (Jöris 2006: fig. 6). Outline shape can be a distinctive characteristic of bifaces, but it is usually described by ostensibly defined, qualitative terms, such as “cordiform” or “subtriangular” (e.g. Doronichev & Golovanova 2003: 88, 89; Schick & Clark 2003: fig. 1.19; Boroń 2006).

In the past few years, landmark-based morphometrics became widely implemented in lithic studies (e.g. Lycett et al. 2010; Iovita 2011; Charlin & González-José 2012; Eren & Lycett 2012). There were approaches using geometric morphometry as an aid in artefact classification (Buchanan et al. 2007), in identifying reduction effects on lithic tools (Thulman 2012) and in evaluating the morphological diversity of assemblages in general (Azavedo et al. 2013). However, the focus of these studies is mainly on finely crafted bifaces, such as Paleo-Indian points. There has been some research dealing with Lower and Middle Palaeolithic handaxes and Keilmesser in this manner, for example, studies by Iovita (2009 & 2010), Archer & Braun (2010), Costa (2010) and Iovita and McPherron (2011), but such approaches still seem scarce.

The aim of this paper is to test the utility of geometric morphometric outline shape analysis in assessing the variability of Late Middle Palaeolithic (LMP) bifacial tools. Keilmessergruppen handaxes and backed knives are highly diverse in terms of morphology. Patterns of their shape variation are often complex and hard to grasp using
classical typological criteria. Typology often uses mixed attributes, such as morphology, function and technological features. The attempt to capture these traits altogether can be confusing, especially when comparing large assemblages (Iovita 2009). This creates a need for an approach focused expressly on the morphology of LMP bifaces.

**BACKGROUND**

**Keilmesser**

Keilmessergruppen backed knives (*Keilmesser sensu* Jöris 2006), were first recognised as a separate typological category by Krukowski (1939–1948). Later on they were formally defined by Chmielewski (1969). Initially, one of the most distinctive features of these artefacts was the paraburin scar resulting from a blow made at the distal end of the tool. This ‘Pradnik technique’ proved to be a convergent technical feature, which emerged independently in geographically distinct regions, probably as a method of resharpening the working edge (Schild & Wendorf 1977; Marks 2002; Solecki 2004). In the group of *Keilmesser* investigated here only two specimens bear the traces of Pradnik technique.

Figure 1. 1) Keilmesser from Wylotne Rockshelter, layer 8/7; 2) Keilmesser from Biśnik cave, assemblage F2

In 1975 Sobczyk (1975) offered an innovative approach to the variability of Polish *Keilmesser* assemblages. Using the method of numeric taxonomy he analysed a group of 100 *Keilmesser* for their mutual correlations according to qualitative and quantitative features. The results showed that the examined *Keilmesser* make up a highly variable, polymorphic group. The study made by Sobczyk was effectively a follow-up of research on the classification of lithic artefacts started by Kozłowski (1972).

Nowadays it is widely accepted that the main reason for the morphological diversity of *Keilmesser* forms was the rejuvenation of the working edge, which induced the shift of their proportions (Jöris 1994; Pastoors & Schäfer 1999; Jöris 2001; Pastoors 2001; Migal & Urbanowksi 2006).

It should be noted that similar analyses of Micoquian *Keilmesser* outline shapes were conducted by Veil et al. (1994), Jöris (2004) and by Iovita (2009 & 2010). From a techno-functional point of view (*sensu* Boëda 2001 & Jöris 2013), studies by Veil and Joris focused mainly on active parts of *Keilmesser*, such as the cutting edge and other elaborated sections. For his part, Iovita used the *Keilmesser* only as a part of his sample. Focusing on the technically active sections seems a reasonable procedure but I think that in case of many *Keilmesser* the cortical areas were left unworked to preserve the natural ergonomics of a blank, and as such they form an element of the overall tool design. Including these sections in the outline shape analysis can have interesting results.

**Handaxes**

The LMP is the period of recurrent appearance of handaxe-rich assemblages in Europe. After diminishing in number at all of the early Middle Palaeolithic sites, handaxes reappear between MIS 5d and MIS 3 (ca 115–35 ka BP) as a distinctive implement of two important cultural entities: *Keilmessergruppen* and Mousterian of Acheulian Tradition (Soressi 2002; Ruebens 2007 & 2013).

There exists a commonly accepted view that a handaxe’s design contains not only strictly functional traits but also carries deeper cognitive and social values, such as the aesthetic sense and symbolic behaviour. These ideas are supported by the relatively large effort invested in the manufacture of handaxes, their complex use-life and characteristic...
Figure 2. Three main morphological types of handaxes in the studied assemblage. Wylotne Rockshelter, layer 6

In the studied assemblage there are various forms of handaxes. Using established nomenclature, types such as triangular, cordiform or lanceolate can be distinguished (see Fig. 2), yet the asymmetry of Keilmessergruppen handaxes sometimes makes the distinction between them and asymmetric knives difficult. Schild, for instance, placed Keilmesser in the wide category of handaxes (Schild & Wendorf 1977), while Hahn (1994) pointed out that Keilmesser and handaxes appear to be closely related typological categories.

There are two models for interpreting the morphological variability of handaxes. McPherron’s model emphasises the role of reduction process on a tool’s form (McPherron 1994, 1999, 2000, 2003 & 2006; see also below), while the model created by White focuses on the impact of raw material on handaxe shape (White 1995 & 1998). These models were originally developed for Acheulian large cutting tools but they are sufficiently broad to be used for other handaxe forms as well. Both frameworks are relevant, since the shape of bifaces was influenced both by resharpening and by raw material properties (Archer & Brown 2010). White’s model will not be taken into account since most of the handaxes, as well as other types of bifaces under analysis, were made of the same type of raw material (Table 1).

**Leaf points**

Leaf point industry is the youngest Middle Palaeolithic unit with bifacial tools. It is observed between ca 50 and 30 ka BP (Kozłowski 1999: 87–89). Formerly, a number of regional groups were distinguished, such as Jerzmanowician in southern Poland (Chmielewski 1964; Mańka 2005) and Altmühlian in Middle Franconia in Germany (Bosinski 1967). With time, the comparison of assemblages and revised chronological setting showed that these groups share common features present at a similar time. Except the bifacially worked leaf points, which became the type fossil for this industry, the most intriguing attribute is the presence in Middle Palaeolithic toolkits of Upper Palaeolithic artefacts such as burins and endscrapers.

The leaf point industry derives from the Keilmessergruppen tradition or the Mousterian with Micoquian Option as defined by Richter (2008–2009). Leaf points appear sporadically in Keilmessergruppen and M.M.O. contexts, also in southern Polish sites like Biśnik Cave (Cyrek 2002: table XVII). Richter emphasises the presence in the final Micoquian of a tendency to produce larger and more perfectly crafted bifacial leaf points, which probably marks the emergence of the leaf point industry (Richter 2009).

The technology of manufacture of leaf points changes significantly through time. They gradually lose their all-over flat bifacial retouch until, in the latest stages of the leaf point industry, the retouch covers only the proximal or the distal end of long, slender blades. This pattern is observable in the younger episodes of occupation of the Nietoperzowa Cave (see Fig. 3) and in Mauern as well (Kozłowski 2004: 400–402).
In this study leaf points are used only as a comparative sample and principal focus is on handaxes and Keilmesser.

Figure 3. Late Middle Palaeolithic leaf points from Nietoperzowa Cave: 1) layer 6; 2) layer 4

MATERIALS

The main sample consists of handaxes ($n = 42$) and Keilmesser ($n = 51$). Their outlines were obtained by scanning illustrations from the monographs of the major LMP sites in southern Poland, namely the Wylotne Rock shelter, Biśnik Cave and Pietraszyn 49 (Table 1). This procedure was applied also by Costa who used illustrations of bone and stone bifaces from Castel di Guido (Costa 2010). Photographs of artefacts are not always available and illustrations provide easily accessible and reliable data on biface shapes.

All the stratified sites examined here are homogenous in terms of assemblage integrity and stratigraphical sequences. The exceptions are Pietraszyn 49, where artefacts were discovered on a secondary deposit, as well as Pietrowice Wielkie 8c and Cyprzanów 3 (see below). Despite this fact the overview of the composition of artefact types from Pietraszyn 49 and their technical features confirms the LMP character of this assemblage and its affiliation to the central European Keilmessergruppen.

The pattern of shape variability in LMP leaf points is clear and comprehensible (see above). For this reason a group of LMP bifacial leaf points ($n = 54$) was included in the analysis for comparative purposes. The points come mostly from well-dated stratified sites such as Nietoperzowa Cave and Mauern (Table 1).

Additionally, two surface finds from upper Silesian sites Pietrowice Wielkie 8c and Cyprzanów 3 were included in the sample. These artefacts were initially recognised as Keilmesser, but in the author’s opinion they lack basic features characteristic of Keilmesser, such as the presence of a back and base opposite to the cutting edge. Comparing these artefacts to a larger sample of Keilmesser will test the morphometric shape analysis as a discriminator of bifacial artefacts that deviate from the general set in terms of technology.

The sample is suitable for testing the outline shape variability of Keilmessergruppen bifaces for two reasons. First, groups representing individual typological categories contain implements of different shapes and sizes, yet they all belong to homogenous assemblages in respect of similarities in technology of manufacture and dating. When assigning artefacts to the typological categories, the author followed the classification proposed by the authors of the monographs (see Table 1). Secondly, the studied series come from different types of site, which gives a more comprehensive view on artefacts’ variability.
Figure 4. Map of the sites containing the studied assemblages: 1) Nietoperzowa Cave; 2) Wylotne Rockshelter; 3) Biśnik Cave; 4) Pietraszyn 49; 5) Cyprzanów 3; 6) Pietrowice Wielkie 8c

Table 1. List of materials used in the study

<table>
<thead>
<tr>
<th>Typological category</th>
<th>Site</th>
<th>Raw material</th>
<th>Site type</th>
<th>Stratigraphic unit</th>
<th>Date</th>
<th>Specimens (n)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Handaxes</strong></td>
<td>Wylotne</td>
<td>Jurassic flint</td>
<td>Rock shelter</td>
<td>5, 6, 8/7</td>
<td>ca 100–60 ka BP</td>
<td>38</td>
<td>Kozłowski (ed.) 2006</td>
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<tr>
<td></td>
<td>Pietraszyn 49</td>
<td>Erratic flint</td>
<td>Open air</td>
<td>-</td>
<td>Undetermined</td>
<td>4</td>
<td>Fajer et al. 2001</td>
</tr>
<tr>
<td><strong>Knives</strong></td>
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<td>Jurassic flint</td>
<td>Cave</td>
<td>5/6</td>
<td>67±15 ka BP</td>
<td>8</td>
<td>Cyrek (ed.) 2002</td>
</tr>
<tr>
<td></td>
<td>Wylotne</td>
<td>Jurassic flint</td>
<td>Rock shelter</td>
<td>5, 6, 8/7</td>
<td>ca 100–60 ka BP</td>
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<td>Kozłowski (ed.) 2006</td>
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<td>Open air</td>
<td>-</td>
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<td>8</td>
<td>Fajer et al. 2001</td>
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<tr>
<td></td>
<td>Pietrowice Wielkie 8</td>
<td>Undetermined</td>
<td>Surface find</td>
<td>-</td>
<td>Undetermined</td>
<td>1</td>
<td>Fajer et al. 2001</td>
</tr>
<tr>
<td></td>
<td>Cyprzanów 3</td>
<td>Undetermined</td>
<td>Surface find</td>
<td>-</td>
<td>Undetermined</td>
<td>1</td>
<td>Fajer et al. 2001</td>
</tr>
<tr>
<td><strong>Leaf points</strong></td>
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<td>Jurassic flint</td>
<td>Cave</td>
<td>6, 5a, 4,</td>
<td>30–38 ka BP</td>
<td>25</td>
<td>Chmielewski 1962</td>
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<td></td>
<td>Ehringsdorf</td>
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<td>Cave</td>
<td>-</td>
<td>Undetermined</td>
<td>18</td>
<td>Kot 2013</td>
</tr>
<tr>
<td></td>
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<td>Cave</td>
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<td></td>
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<td></td>
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</table>
METHODS

Artefact orientation, landmark configuration and the Procrustes analysis

The author used a standard geometric morphometric method of outline shape analysis based on landmarks. Before the actual analysis, a set of procedures, generally based on data processing, had to be carried out.

To project the outline shape, the illustrations of the artefacts were scanned with a Canon CanoScan LiDE 210 scanner at 400 dpi. The image of each artefact was extracted as a single jpg file and oriented in GIMP according to its axis of symmetry. To allow further comparisons between shapes, all outlines had to be oriented in the same manner. The method of orientation applied in this study was first described by McPherron & Dibble (1999) and improved upon by Costa (2010). In it all the bifaces are oriented around their long axis of symmetry so that the longest orthogonal lines drawn from a central line were equal in length (Costa 2010: fig. 2.1b). The tip of a biface was used as the point from which the outline was drawn along the biface’s perimeter. This outline will then be transformed into a set of equidistant landmarks.

After performing the orientation a thin plate spline file was created in TpSutility program (Rohlf 2006). This stores all the images in one tps file and allows a further digitisation of the images. The tps file with all the images was then opened in TpSDig (Rohlf 2004), a program used mainly for placing landmarks on specimens.

In natural sciences when the morphology of living or fossil organisms is taken into account landmarks are often placed on relevant biological structures (e.g. Querino et al. 2002). Of course one can do the same for lithic artefacts, such as their tip or base, but this way the complex shape of bifaces is reduced to just a few landmarks. In the studied case the best way to capture the outline shape is to set a number of landmarks around the perimeter of an artefact. To allow further comparison between tool shapes the landmarks must correspond to each other, i.e., they need to be placed at equal distances and according to a standardised configuration. Using the TpsDig outline tool it is possible to draw an outline from the tip, along the perimeter of an artefact, and then transform it into a set of equidistant landmarks (Costa 2010). The number of entered landmarks is left for the user to choose. Costa used 75 points (Costa 2010: 27), while Iovita employed 60 landmarks (Iovita 2009). These numbers are chosen on a trade off between the labour-cost of hand-digitising and the accurate delineation of artefact shape. I decided that 100 landmarks would describe the outline shape with a greater accuracy since
LMP bifaces contain large natural surfaces and are often irregular. After assigning the landmarks for each specimen the tps data were opened with PAST (Palaeontological Statistics), a program enabling statistical shape analyses (Hammer et al. 2001).

Landmarks are subject to several kinds of movements in two-dimensional space, such as rotation and translation (Richtsmeier et al. 2002). These may affect the correct orientation of specimens and cause errors during a comparison of artefact shapes. One should also bear in mind that some of the digitised outlines were represented in a different scale than the others. To eliminate landmark displacements a Procrustes analysis must first be conducted. Procrustes analysis is a set of mathematical operations which transforms the matrix of XY coordinates so that translation, rotation and the difference of scale is eliminated from the assemblage (Rohlf & Slice 1990) (Fig. 1). Additionally all outlines are superimposed around a centroid, which is the 0,0 coordinate on the XY axis (Hammer & Harper 2006). This operation subtracts the mean shape referred to as “consensus” from all the coordinate values, allowing for further tracking of shape deformations of specimens in relation to the consensus shape. Superimposition scales bifaces’ dimensions to a common centroid, equalising their size, while preserving the original shape (Jungers et al. 1995).

**Table 2. Eigenvalues and the percentage variance of the selected principal components generated singly for each typological group**

<table>
<thead>
<tr>
<th>Knives</th>
<th>PC</th>
<th>Eigenvalue</th>
<th>% variance</th>
<th>Handaxes</th>
<th>PC</th>
<th>Eigenvalue</th>
<th>% variance</th>
<th>Leaf points</th>
<th>PC</th>
<th>Eigenvalue</th>
<th>% variance</th>
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<td>37,169</td>
<td>PC</td>
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<td>23,041</td>
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<td>0,0002431</td>
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<td>PC</td>
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<td>3,64E-05</td>
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</table>

**Principal component analysis**

Bifacial tool shapes differ in many variables. The best way to explore this variability when dealing with multiple landmark data is to conduct principal components analysis (e.g. Gowlett 2006).

The set of landmarks is a K\times M matrix, that is, a matrix of K number of landmarks in M dimensions (Dryden & Mardia 1998). It is
expected that some regions of the tool outlines will overlap since they generally belong to the same typological category, but patterns of their variation and covariation are often complex and difficult to interpret. The purpose of PCA is to simplify those patterns and make them easier to interpret by reducing the number of shape variables (Zelditch et al. 2001: 156). PCA transforms the matrix of landmarks so that most of the variation is described by principal components. This method serves as a useful indicator of patterns in complex sets of data, characterised by numerous variables. Where knives and handaxes are expected to differ in several factors it is safe to apply PCA, which will hopefully identify patterns in their shape variability.

RESULTS

The first two principal components describe 56.021% and 18.544% of the whole variance and only those PCs were taken into account during analysis (Table 3). The number of generated PCs is equal to the number of all specimens ($n = 147$) but most of them hold very little of the overall variance, therefore 11 PCs are presented in Tables 2 and 3 for comparative purposes.

To compare the eigenvalues and the percentage variance between the assemblages, a set of eleven principal components was also generated for each typological group (Table 3). The percentage variance values indicate that

To test the accuracy of observations, a 95% ellipse will be applied as a supplement to the PCA analysis. The ellipse is drawn based on the assumption that the data is subjected to a two-dimensional normal distribution. The orientation of an ellipse depends on the correlation coefficient between the variables, for example, the longer axis of an ellipse is approximately imposed according to the regression line of values. The probability that a new value will fall in the range of the ellipse (for instance 0.95) is the parameter determining its size (Tracey et al. 1992). 95% ellipses can serve as a discriminative tool, indicating which specimens are deviating from the range of shapes predicted for each typological group.

Leaf points are the most uniform group in terms of outline shape, as the first two principal components describe 76.716% of the overall variance. Knives are the most variable typological group in which the values of the percentage variance are more evenly distributed between the individual principal components. This implies that there is no clear trend in the distribution of their outline shapes.

PC1 axis shows the regression of the most expanded tool shapes towards the most contracted ones. It is hard to define the range of distribution shown by PC2 since there are too few specimens scattered according to this principal component (Figs 7 & 8). Most of the knives are distributed according to PC2, but

Figure 7. Plot showing the result of PCA analysis with convex hulls. Outlines of artefacts with the most extreme values were placed on the plot with their thin plate spline deformations

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the reason for this arrangement is unclear.

Knives seem to be scattered in a random manner, without indication of a significant pattern of distribution. However, some trends can be noticed by observing the shape deformations of individual Keilmesser landmarks according to the consensus shape (see Fig. 6.). It is apparent that most deformations are located at the back or in the basal parts of Keilmesser.

The position of handaxes on the PCA plot confirms a shift of proportions from expanded shapes with an oval contour (i.e. Fig. 7, 8: specimen 107: Fajer et al. 2001: Fig. 3; specimen 127, 128: Targosz 2006, Plate 42 and 46) through forms with straight edges and a triangular contour (i.e. Fig. 7, 8: specimen 130, 123: Boroń 2006, Plate 99; Targosz 2006, Plate 40), to handaxes with straight or slightly concave edges, which are intensively elaborated with flat, surface retouch (Fig. 7, 8: specimens 108, 110, 142: Fajer I in. 2001, Fig. 4a; Targosz 2006, Plate 43; Figure 8: 110, 126, 144: Targosz 2006, Plate 44, 45; Boroń 2006, Plate 104). It is notable that handaxes and leaf points are similarly distributed, mainly according to PC1, which generally shows the transition from broad, oval shapes to the most elongated specimens.

None of these sets of artefacts is exclusive in their plan shape, and mutual relations occur between each group. The strongest connection seems to be between knives and handaxes, as most of them are located in the same area designated by the 95% ellipse (see Fig. 8). The ellipse also shows that two knives are located clearly outside of its perimeter. These are the artefacts from Cyprzanów 3 and from Pietrowice Wielkie 8 (Fajer et al. 2001: fig. 19b).

**DISCUSSION**

It is interesting that the Keilmesser are scattered randomly on the plot. If reduction affected their proportions it should come as a regression on the plot, since the studied assemblage comprises specimens which can be considered as initial (i.e. Fig. 1; Fig. 8: specimens 75, 96: Targosz 2006: plates 54 & 55; specimen 102: Cyrek 2002: plate IX) as well as exhausted (i.e. Fig. 8: specimens 73, 92 & 105; Milewski 2006: plate 16 & 26; Cyrek 2002: plate VIII: 1). On the basis of these observations it is hard to conclude that reduction was the main reason for Keilmesser outline shape variability.

![Figure 8. PCA plot with 95% ellipses](image-url)
Table 3. Eigenvalues and the percentage variance of the selected principal components generated for knives, handaxes and leaf points altogether

<table>
<thead>
<tr>
<th>PC</th>
<th>Eigenvalue</th>
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Most of the variance in the Keilmesser assemblage is produced by the irregularities of natural surfaces in the back and at the base of these tools (Figs 1 & 2). Landmark vectors show that regions of the tip and the cutting edge are held relatively constant, while the back and the base undergo serious deformations as compared to the consensus shape (Fig. 6). This indicates that knives were made of nodules of raw material that differed in sizes and shapes and this probably affected the overall form of the finished tools. This diversity can be simply explained by ergonomic requirements. Given the numerous tasks that Keilmesser were involved in (Rots 2009: 44–48), the prehensile parts were clearly extended in comparison to handaxes, simply to get a better grip on the tool when performing different activities. Therefore it seems that the available raw material, and specifically its form, had a major influence on Keilmesser shapes.

These results are generally similar to those obtained by Iovita (2010). By applying a variant of morphometric outline shape analysis (elliptic Fourier) this researcher learned that Keilmesser may have been reduced selectively due to the position of their prehension parts or hafting elements. That is why the trajectories of their shape change through reduction are not so easy to observe. In my opinion a more detailed statistical shape analysis would help to overcome this difficulty. If the natural sections of Keilmesser are responsible for blurring the overall view of their variability then the analysis should focus strictly either on the prehension areas or on the active parts of the tool, which were more likely to have been exposed to the reduction process.

The position of two Keilmesser falls clearly outside the 95% ellipse (Fig. 8: specimens 57 & 58). These are the surface finds from Pietrowice Wielkie 8c and Cyprzanów 3. Their position on the plot confirms that they deviate from the outline shape predicted for Keilmesser.

The relationship between the assemblages of knives and handaxes seems to confirm the genetic relationship connecting these implements emphasised by Hahn (1994). Handaxes show a clear regression from cordiforms or irregular ovate specimens, through triangular forms, toward slender handaxes with a pronounced tip. In my opinion, this pattern may have been caused by continuous resharpening and/or reduction. It is especially apparent in case of the transition from irregular ovate to triangular handaxes.

Acheulian handaxes showed a pattern of reduction involving mainly the rejuvenation of the tip. This resulted in the transition from a pointed to an oval morphology of their contour (McPherron 1995, 1999, 2000 & 2003; see also Iovita & McPherron 2011). If reduction was the reason for the pattern revealed by this study than in case of Keilmessergruppen handaxes an opposite trajectory can be
observed. It seems that the reduction was aimed at resharpening or simply losing the material from the edges more than from the tip (see Fig. 6). In general, this may have had an influence on handaxe outline shape, causing the transition from cordiform or ovate morphology towards handaxes with straight or concave edges and a pronounced tip (Fig. 2). Nevertheless the applied method does not take artefact size into account; therefore additional metric study of Keilmessergruppen handaxes is needed to resolve this issue.

Our analysis also revealed an interesting pattern in the leaf point assemblage. The width of these implements undergoes evident contraction, which obviously is due to the changes in leaf point manufacture mentioned earlier. This shift of form appears to be regular and affects mostly the edges of the leaf points while the proximal and distal areas remain relatively constant, as if the intention was to maintain elongation as well as the tip and base within the same proportions (Fig. 6; 3). At this point it is hard to properly interpret this pattern in shape variation and further research on this subject needs to be conducted. Nevertheless the author would like to emphasise that this type of change in leaf point morphology may be connected with adaptive changes in lithic projectile technology, such as the transition from thrusting to hand cast spears (Hughes 1998).

CONCLUSIONS
The results of the morphometric shape analysis indicate that there may exist two types of change in artefact outline shape: synchronic, involving the reduction of tool proportions caused by repeated resharpening in handaxes, and raw material selection in Keilmesser; and diachronic, based on alterations to the design of tools.

The method deals poorly with exploring the variability of artefacts with large natural surfaces. The results show that there is no observable trend among Keilmesser outline shapes. Natural sections tend to produce variance since they are often irregular, and this may disrupt the actual patterns of shape change. I believe that this method may be applied to Keilmesser, but with some modifications. Placing the landmarks on active parts of tools can have a positive effect.

Applying 95% prediction ellipses also served its purpose in discriminating artefacts from extraneous contexts. The knives from surface finds were placed clearly away from the majority of specimens and were left out from the general set.

Although this method is limited because it takes no account of the technical and metric features it may be useful in constructing holistic models of artefact shape reduction (occurring synchronically or diachronically). Nevertheless, to avoid misinterpretation, one should bear in mind two limitations encountered in the course of the discussed analysis. First, the method serves best when applied to quantitatively large assemblages. Lower and Middle Palaeolithic bifaces are often irregular, and a larger sample (one preferably assembled from several sites) will allow for a more comprehensive view. Secondly, including a test sample of different provenance than the main assemblage can assist the interpretation of shape change trajectories and bring in potentially interesting results.

REFERENCES
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Capsule of Trichogramma pretiosum Riley (Hymenoptera: Trichogrammatidae). 


