DISCUSSION

The Late Middle Palaeolithic in Central and Eastern Europe is often characterised by lithic inventories comprising asymmetric tools. One of these artefact categories are the well-known *Keilmesser*. *Keilmesser* are defined by an interaction of certain technological and typological characteristics. From exactly the combination of both, technological and typological features, *Keilmesser* are well studied, resulting in a multitude of interpretations and models not only concerning production and manufacturing strategies, but also about tool function and use (**tab. 1**). Based on the analysis of *Keilmesser* inventories from three relevant, central European sites, given interpretations were called into question. A multidisciplinary approach served the purpose.

TOOL STANDARDISATION

Tool dimensions and the effect of reduction

Keilmesser are referred to as highly standardised tools (e. g. Veil et al. 1994; Richter 1997; Jöris 2001; 2006; 2012; Wiśniewski et al. 2020) with (recurrent) stages of reduction or shape transformation. Their manufacture, reduction, (re-) sharpening and shape transformation seems to follow an underlying socially learned and transmitted concept. The tool dimensions provide a first impression of the degree of tool standardisation. Relevant are absolute sizes such as the length, the width and the thickness; proportional measures such as the ratio between the length and the width and lastly the perimeter measures from the artefact outline. Thereby, indications can be found in each assemblage and in the comparison of the three assemblages. When looking at the results from Buhlen, Balve and Ramioul individually, it becomes evident that the dimensions, for example the length, the width and the thickness do range around certain measurements, but the range of these absolute dimensions can likely be explained as a consequence of diverging use-life histories (Richter 1997; Jöris 2001; 2006; Pastoors/Schäfer 1999; Pastoors 2001). More interestingly, the variability of dimensions (including proportional ratios) from the artefacts from the three sites does not differ significantly within and across assemblages. On the contrary, the results indicate similar ranges for the length, the width, the thickness as well as a rather standardised thickness of the tools' back in the three studied assemblages. Not only the ranges are similar, also the arithmetic mean values are nearly identical. Therefore, the morphological concept of a *Keilmesser* seems to be represented in the studied assemblages, characterised by artefacts with similar dimension ratios. This becomes more evident when looking at the length-width ratio (**fig. 158**) of the analysed samples. The analysis supports the idea that the individual *Keilmesser* represent artefacts with diverging tool biographies. Consequently, *Keilmesser* in their preserved form reflect a morphology, shaped by previous use and reduction. Due to use, a resharpening of the tools is eventually inevitable, resulting in changing dimensions, but not in its technological design. In *Keilmesser*, resharpening is seen as an inherent part of the tool concept (Richter 1997; Jöris 2001; 2006; 2012; Weiss et al. 2018). Resharpening influenced thereby mainly the length and the width of the tools. Nevertheless, the dimensions seem not to change randomly, but the shift in the length and width dimensions follows a ratio. This indicates repeated standardised phases of retouch, mostly in the distal part of the tool's active edge. Iovita (2010) already suggested after analysing artefacts from Buhlen, that *Keilmesser* change isometrically

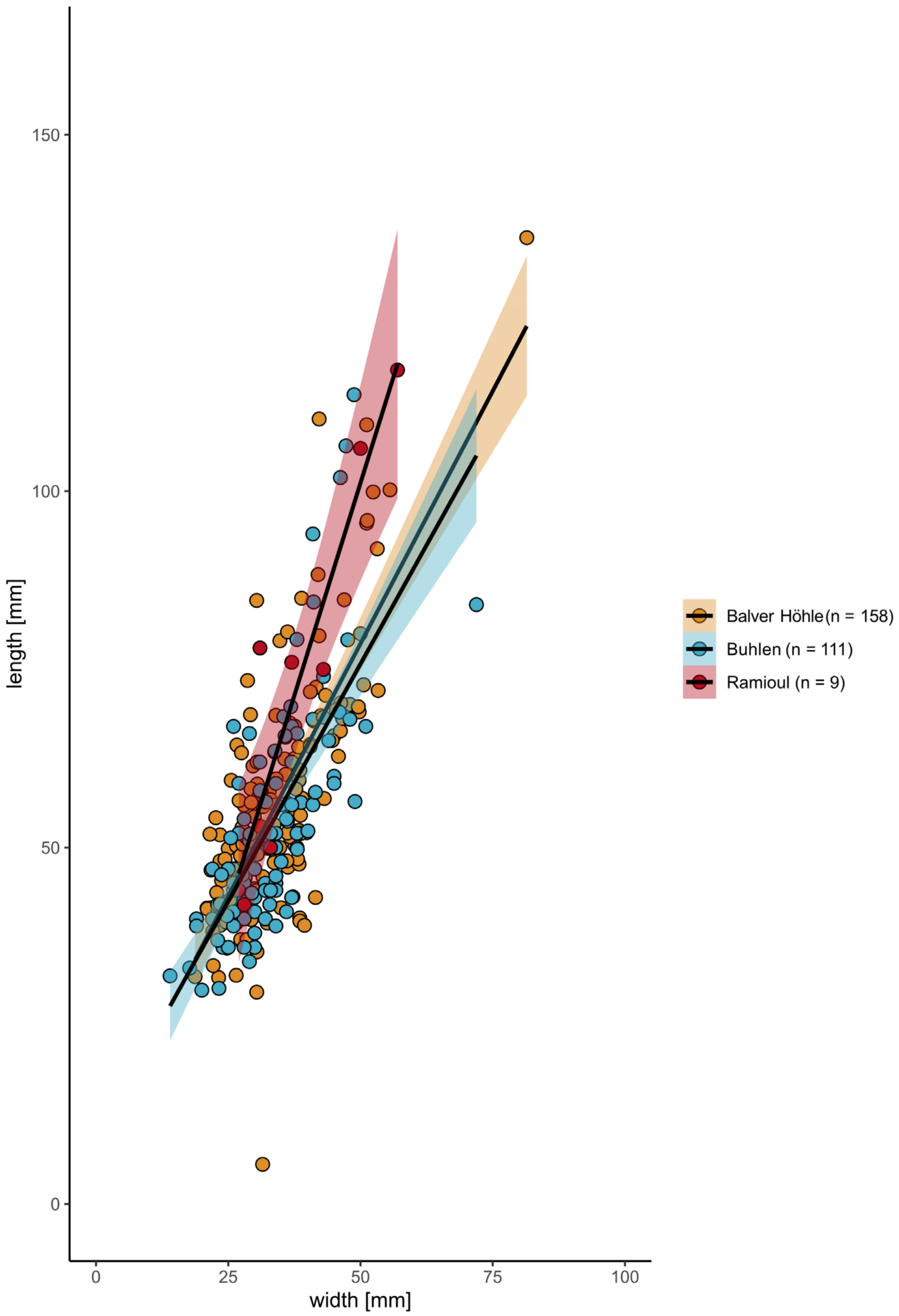


Fig. 158 Length-width ratio of all complete *Keilmesser* from Buhlen, Balver Höhle and Ramioul. The regression line per site shows the overall trend of the data set.

in relation to their perimeter sections (base + back, distal posterior part and active edge). Reduction has thus no direct impact on the length-width ratios of the tool outline (Jöris 2001).

According to their morphological characteristics, also the so-called *Keilmesser* tips are part of this *Keilmesser* tool concept. *Keilmesser* tips could be documented for the assemblages from Buhlen and Balve. The analysis of the dimensions confirmed that *Keilmesser* tips are substantially shorter, comparable with the shortest complete *Keilmesser*. However, the *Keilmesser* tips display the same length-width ratio and fit in the size variability of *Keilmesser* (**figs 49-50**). Thus, also here, the techno-typological analysis supports the theory that, when a point was reached so that resharpening of the tool was not possible anymore, *Keilmesser* were transformed into other shapes by removal of their tips. According to Jöris (2001; Jöris/Uomini

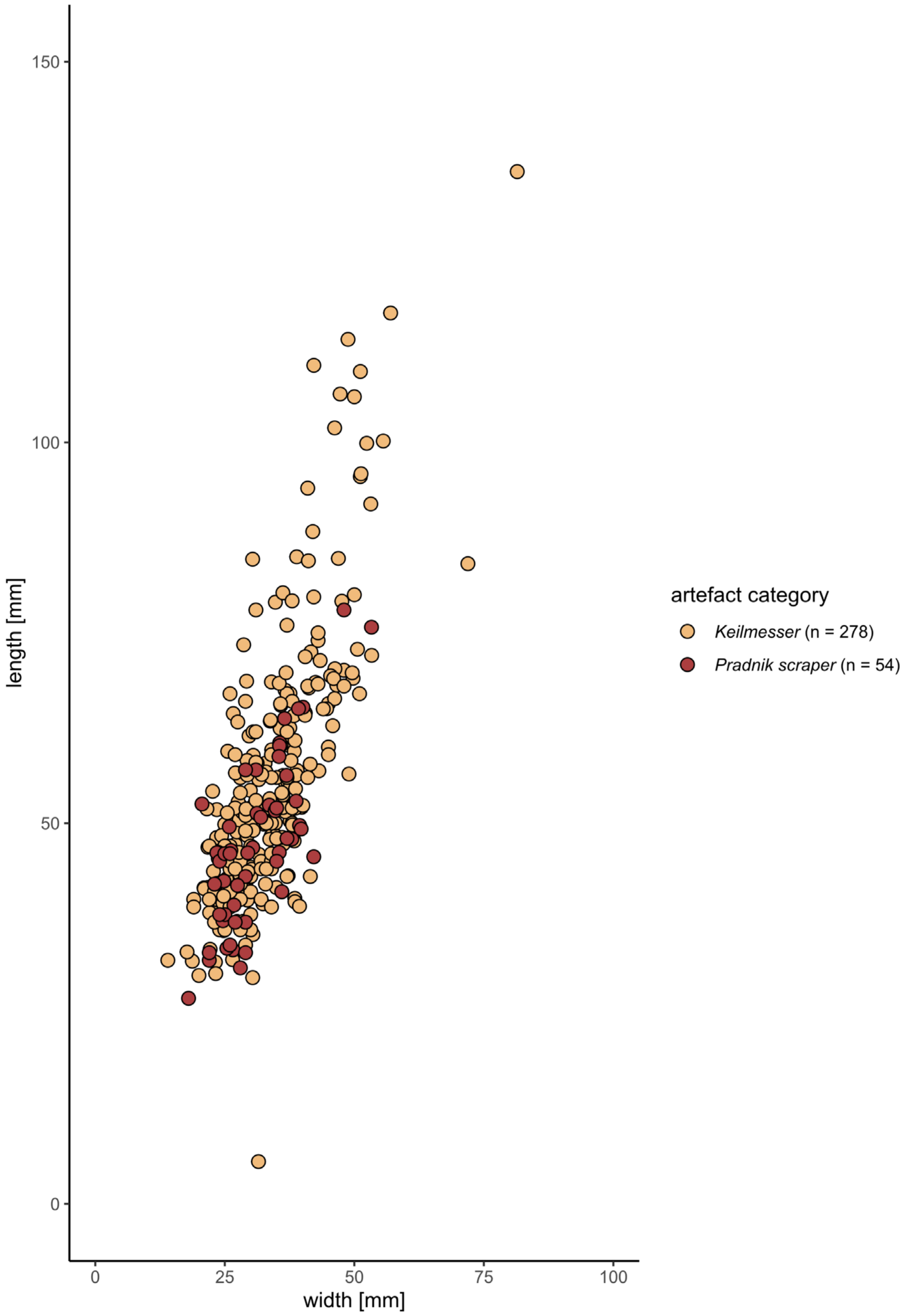


Fig. 159 Length-width ratio of all complete *Keilmesser* and *Prądnik scraper* from Buhlen (n = 111, n = 24), Balver Höhle (n = 158, n = 27) and Ramioul (n = 9, n = 3).

2019) additional thinning (back and distal posterior part, convex upper surface) and lateral sharpening led to the desired shape.

Moreover, also the dimensions of the *Prądnik scrapers* are comparable to the ones from *Keilmesser* (**fig. 159**). However, the ratios of *Keilmesser*, including the shortest and longest *pieces,* scatter more widely than the ones from *Prądnik scrapers*. The variance in length as well as in thickness of the back is smaller and thus to emphasise. However, the quantity of studied *Keilmesser* is also bigger compared to the studied *Prądnik scraper* assemblage, which could also affect these results. Nevertheless, *Prądnik scrapers* provide the impression of varying less in their dimensions and appearing slightly more static compared to *Keilmesser*. Contrary to *Prądnik scrapers*, *Keilmesser* display more often traces of resharpening and reworking accompanied with decreasing dimensions. Indications of reworking such as the removal of the tip as described for the *Keilmesser* could not be documented for the *Prądnik scrapers*.

Shape variability in *Keilmesser*

In line with these thoughts are the observations made regarding the classification of the different *Keilmesser* shapes. Based on the measurements of the individual perimeter sections, the relation between these sections could be illustrated in a size-independent comparison together with the defined *Keilmesser* shapes (**fig. 84**). In this way, the previously expressed assumption (see also Urbanowski 2003; Migal/Urbanowski 2006; Jöris 2012; Jöris/Uomini 2019; Weiss 2020) could be strengthened: based on their morphometry, there are no strict *Keilmesser* shapes. The different shapes might be the combined results of the natural variability of the raw material and its shape, the blank type used as well as the result of tool modification during and after use. Resharpening and reworking most often effects the distal posterior part and the active edge (Migal/Urbanowski 2006; Iovita 2010; Jöris/Uomini 2019; Weiss 2020). The perimeter proportions shift, leading to a slight change in shape. These observations contradict the idea of shape variability as a chronological sequence (Bosinski 1967; 1969). Instead, the classification of the *Keilmesser* shapes should be seen as an artificially constructed categorisation. Although these tools display a certain shape variability, they all have morphological features in common, which can be summarised under the concept *Keilmesser*.

Transmission of skills and knowledge

The results gained through the techno-typological analysis of the three sites Buhlen, Balver Höhle and Ramioul build on existing evidence concerning the given degree of tool standardisation in *Keilmesser*. The results referring to the tool dimensions, attributes and shapes indicate that *Keilmesser* were manufactured and curated following a certain scheme. This is indicated on the one hand by the data from the sites respectively and on the other hand through the data of the inter-site comparison, which led to nearly identical results. The similarities between the assemblages from Buhlen, Balve and Ramioul imply that the standards, which define the tool production and curation to a certain degree, are not only present in one of the sites, instead, they can be documented in all assemblages. What becomes evident is, that these standards must have been established and maintained over extended periods of time, rooted in the technological behaviour of Neanderthals (Jöris 2004; Ruebens 2013; 2014; Kozłowski 2014; for a contrasting opinion see Iovita 2014; Weiss et al. 2018). The sites Buhlen and Balver Höhle do reflect long, recurrent settlements of human occupation. Due to the palimpsest situation, an extended temporal depth is reflected in the archaeological assemblages. Based on these similarities in the artefacts, *Keilmesser* likely indicate regional, common features or regional technological traditions. Traditions are the result of a continuous transmission of for instance action pattern and social conventions. These include simple actions such as the manufacturing of tools or complex ones such as language. The social component is indispensable for the development of traditions. The formation of traditions requires social interaction (see Shennan 2008 for a review). Traditions are not inherited, they have to be learned and passed on either horizontally (within a social group) or vertically (across generations). The standardised production of a *Keilmesser* presumably reflects the result of such social interaction (Jöris/Uomini 2019). The manufacturing and the curation of *Keilmesser* has likely been a skill passed on from generation to generation. This would explain the similarities within the tools, described as underling tool concept, visible not only within the temporal depth of each site, but also across assemblages as the inter-site comparison emphasises. It is exactly this constant transmission of knowledge, action patterns or conventions across generations that defines traditions (Langlois 2001; Lycett/Von Cramon-Taubadel/Eren 2016; see also Shils 1971; Handler/Linnekin 1984).

TOOL DESIGN: TECHNOLOGICAL CHOICES AND EDGE DESIGN

The *Keilmesser* concept

Tool design reflects conscious and unconscious human decision-making as part of human cognitive behaviour. *Keilmesser* with their complex and sophisticated morphology offer the possibility to investigate several aspects related to tool design. Some of these aspects have been addressed within this project. The first point to mention is the raw material choice for the tool production, giving insights into technological and ecological adaptations. The fact, that the shape of the raw material was often an integral part in the tool manufacturing concept, has been stated several times (Jöris 2001; 2006; 2012; Frick/Heckert 2019; Jöris/Uomini 2019; Delpiano/Uthmeier 2020). This could be already demonstrated by Jöris (2001) for Buhlen, but the same approach concerning the tool production is reflected in the artefacts from Balve and Ramioul, too. Nearly 70 % of the analysed *Keilmesser* could be classified as core tools (also in the sense of raw pieces), while in only 5.5 % of the cases a flake was used as a blank. In line with this observation are the results concerning the morphology of the back. In total, for more than two thirds of the studied tools (68.0 %), a cortical back could be documented. The data suggest that the natural morphology of the back was already considered from the tool production onwards and the raw material was accordingly selected. Since the silicified schist, in Buhlen, but also in Balve, appears regionally as angular, barely rounded river pebbles (Jöris/Uomini 2019), the raw pieces could directly be modified by retouch. *Keilmesser* from Ramioul, which are mainly made of flint, are not an exception. Also, these artefacts are characterised by a mainly natural and cortical back.
A second aspect related to tool design is the *Keilmesser* morphology created during the manufacturing process. This topic was already touched on in the previous subchapter, but should be discussed further here. According to Weiss et al. (2018; see also Jöris 2004; Frick/Herkert 2019; Delpiano/Uthmeier 2020), *Keilmesser* do reflect a high shape variability (compared to e.g. hand axes, bifacial points or scrapers) but are standardised in their perimeter sections base and back, distal posterior part and the active edge. As explained before, the artefacts do vary in their shape, especially in their length and width dimensions. Moreover, the tools can be, based on their morphology, ascribed to (artificially categorised) *Keilmesser* shapes. The description of *Keilmesser* as tools with a high shape variability is thus not unsubstantiated. Nevertheless, the characteristics or the morphological definitions of *Keilmesser* are based on their attributes and perimeter sections. Interestingly, the analysis of the perimeter sections of the studied assemblages showed the following: the relation between the base and back as well as the distal posterior part seems to be highly dependent. The smaller the distal posterior part, the larger the dimensions of the back and the base. Regardless of this, the length of the active edge is nearly constant. These findings are supported by the observation from Weiss et al. (2018), stating that the distal posterior part is the more variable part in the tool morphology (see also Bosinski 1969).
Additionally, edge angle maintenance is seen as a crucial and determining factor in the design of *Keilmesser* (Iovita 2010; 2014). Following the ideas by Iovita (2010) and Weiss (2020), edge angle maintenance does not change the presence of the individual perimeter sections. Meaning, the ratio between the sections is

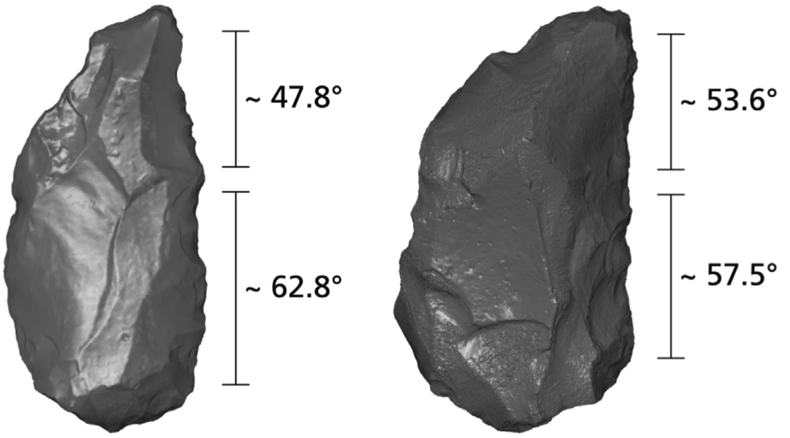


Fig. 160 3D scan of a *Keilmesser* modified by the application of the *Prądnik method* (left; Balve, ID MU-202) and of a *Keilmesser* without this modification (right; Balve, ID MU-197), illustrating the average edge angle in the distal and proximal part of the tool (calculated with the »best-fit« procedure; mean value of section 2 to 4 and distance 3 to 6).

interpreted as needed in order to retain the tool functionality (Weiss 2018). Is it possible to say that the focus of the *Keilmesser* design is concentrated on the active edge and the maintenance of the active edge angle? Within this project, the techno-typological analysis did not go that far in-depth in order to reconstruct retouch sequences or resharpening trajectories. However, this topic can also be addressed from the edge design point of view, including the study of edge angle variance. As common for *Keilmesser*, the active edge of the studied artefacts is most often bifacially worked (76.4 %), sometimes semi-bifacial (18.8 %) and only rarely unifacially worked (3.33 %). Moreover, the majority of *Keilmesser* (60.8 %) are modified by the application of the *Prądnik method*. The result of the modification is usually seen as the production of a stable, straight and / or acute active edge (Jöris 2001; 2006; Frick et al. 2017; Frick / Herkert 2019; Jöris / Uomini 2019). While this is visually recognisable and surely the case, other hypothesis are not so easy to evaluate. One of these hypotheses presumes a reduction of the edge angle by the application of the *Prądnik method*; the other suggests the creation of a bipartite morphology along the edge for differing functions (e. g. cutting and scraping). With the help of the acquired data concerning the edge angles, the first hypothesis can be tested, however, the second hypothesis cannot conclusively be addressed solely with this data, but can be with the results from the use-wear analysis.

Keilmesser edge design

The general results from the edge angle measurements taken from all *Keilmesser* indicate a correlation between the removal of a *Prądnik spall* and an acute edge angle. *Keilmesser* with a modification through the *Prądnik method* display on average a lower, sharper edge angle in the distal tool area than *Keilmesser* without the modification. However, this difference is not immense, usually ranging between a few degrees and rarely exceeding ten degrees. In order to illustrate these results, two examples are given. The first example is a bifacially retouched *Keilmesser* with a clear *Prądnik spall* removal. For this *Keilmesser* from Balve with the ID MU-202 (**fig. 160**) an edge angle of 47.8° could be calculated (»best-fit« procedure; mean value of section two to four and distance three to six) for the distal part of the active edge, where the *Prądnik spall* was removed. The proximal part of the active edge shows an increased edge angle value of 62.8° (»best-fit« procedure; mean value of section five to nine and distance three to six). The second example describes a *Keilmesser* with a bifacial edge retouch, but without any further modification. The edge angles have been calculated in an identical way as noted for the first example. For this *Keilmesser*, *Keilmesser* MU-197 from Balve (**fig. 160**), an edge angle of 53.6° was calculated for the distal and an edge angle of 57.5° for the proximal active edge area. Hence, this *Keilmesser* also shows lower values in the distal tool area, but the variance is smaller. In general, independent of a *Prądnik method* modification, this is a trend documented for all *Keilmesser*. The calculated data illustrates a shift in the edge angle towards higher values from the distal to the proximal part of the tool. Following this, the active edge of *Keilmesser* is more acute in the distal tool area than in the proximal one. Thus, the data analysis supports the theory that the application of the *Prądnik method* reduces the edge angle and leads to a more acute active edge in the area of the removal in the distal part of the tool. This is also in line with other research, demonstrating that the application of a similar method to remove lateral tranchet blows, changed the angle of the tool's active edge by about 10° (Zaidner/Grosman 2015; Prévost/Centi/Zaidner 2020). The researchers concluded the production of a regular, straight and sharp edge as the aim of this tool modification. The second theory about the edge angle design of *Keilmesser* suggested a bi-functional morphology (Jöris 2001; 2006; Frick et al. 2017; Frick/Herkert 2019).

As mentioned above, the distal active edge area of *Keilmesser* commonly displays a more acute edge angle as the proximal area. The acuteness of edge angles often plays a role in the interpretation of the tool's function. Different ranges of edge angle values are thus associated with certain tasks, reflecting technological variability. A comparison with modern cutting edges can underline this aspect. Modern cutting and splitting implements are task specific designed. The values range commonly from low edge angles with less than 20° (e.g. razor blade, scalpel), medium values up to 40° (e.g. Japanese knife, standard cooking knife) to higher edge angles around 50° and 60° (e.g. hatchet, axe) (Hainsworth/Delaney/Rutty 2007; see also ISO 8442-5). Similar functional classification is assumed for Palaeolithic tools. Edge angles below 60° count as acute edge angles (Veil et al. 1994). An ascribed function could be cutting. Edge angles above 60° are more often associated with tasks such as scraping and carving. Based on the calculated edge angle, the interpretation of tools with bipartite morphology along the active edge and bipartite function cannot be refuted for the majority of analysed *Keilmesser* from the assemblages.

Tool handling

Another aspect of tool design, also related to tool functionality, concerns the tool handling. Due to their morphological concept, *Keilmesser* are usually interpreted as handheld tools (Jöris 2001; Frick et al. 2017; Frick/Herkert 2019; Jöris/Uomini 2019). Sometimes, the perimeter sections are also used to infer functional units (Iovita 2010; Weiss et al. 2018; Frick/Herkert 2019; Weiss 2020). Thereby, the base and the back fulfil a prehensile function, the distal posterior part is described as an edge connecting to the tip and used, among others, as a striking platform for thinning. The retouched active edge is seen as the active zone. Assuming the base and the back are the prehensile part of the tool, then, in the case of hafting, the presence of use-wear traces should confirm that. To current knowledge, the only published results of use-wear analysis on *Keilmesser* have been performed on artefacts from the Late Middle Palaeolithic site Sesselfelsgrotte (Rots 2009). From the n = 14 analysed *Keilmesser*, Rots interpreted four of these tools as possibly hafted. These findings cannot be transferred to the results obtained during the analysis of the studied *Keilmesser* from Buhlen, Balve and Ramioul. Based on the observed use-wear traces, hafting can likely be ruled out. None of the different types of the documented use-wear traces could clearly be correlated with hafting, neither due to the location of the traces. Individual artefacts show traces at remarkable positions. However, none of these traces is conclusive in a sense that the location of the traces is consistent on the dorsal and ventral artefact surface. Even so, one example should be given here even so. This example is not classified as *Keilmesser*, but as a *Prądnik scraper*. *Prądnik scrapers* do not reflect deviating results concerning hafting. The tool with the ID BU-099 is a unifacially retouched *Prądnik scraper* from Buhlen (**fig. 161**). The traces are

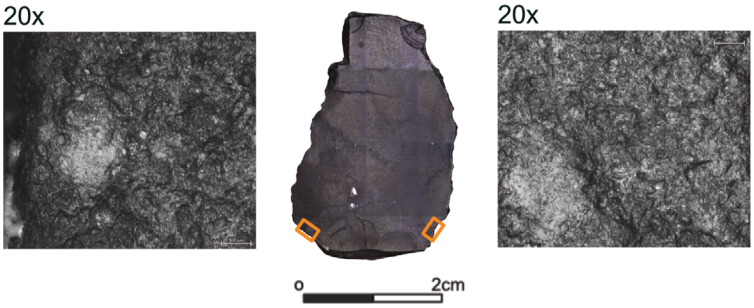


Fig. 161 EDF stitching image of the ventral surface of a *Prądnik scraper* (Buhlen, ID BU-099). The images on the left and right show use-wear traces (images are taken with a 20× optical objective).

located on the ventral surface of the tool in the proximal area to the left and right of the bulb. The traces are not located on exposed areas and are difficult to relate to potential use. Nevertheless, for an interpretation as a hafted tool, these indications are too limited. Thus, the use-wear analysis performed on tools from Buhlen, Balve and Ramioul supports the theory that *Keilmesser* as well as *Prądnik scrapers* are handheld tools.
To summarise, the tool design of *Keilmesser* includes certain technological choices (e.g. raw material and blank selection) combined with functional aspects (e.g. edge retouch), often described as the *Keilmesser* concept (Jöris 2001; 2012; Jöris/Uomini 2019; Weiss et al. 2018; Frick/Herkert 2019; Weiss 2020). The recurrent application of this concept during the manufacturing, the curation and the reworking of the tools convey the idea of standardisation.

Prądnik scrapers **and the** ***Keilmesser*** **concept**

Next to *Keilmesser*, *Prądnik scrapers* as an asymmetrical artefact category have also been addressed within this project in order to investigate these tools more closely. When considering the *Keilmesser* concept not as a rigid one, but as one that combines the mentioned aspects and attributes, how do *Prądnik scrapers* fit into this concept? *Prądnik scrapers* do share morphological traits with *Keilmesser* (Jöris 2001; Jöris/Uomini 2019). In the case of the three studied assemblages, the tools were made of the same raw material. Despite this, the vast majority (88.9 %) of *Prądnik scrapers* are produced from flakes. The flakes, however, seem to be selected carefully, since more than half of the studied artefacts display an asymmetric shape. Additionally, some items illustrate cortical or natural backs, sometimes combined with minor retouch (29.6 %). Other tools show modification, indicating an intentional blunting of the edge in the posterior tool part, giving the impression of the preparation of an »artificial back«. The opposed active edge is mostly not bifacially retouched (13.0 %), as it is in the case for *Keilmesser*. Most of the *Prądnik scrapers* do have a unifacially retouched edge (40.7 %), some a semi-bifacially retouched edge (37.0 %). Furthermore, these scrapers are modified by the application of the *Prądnik method*, which is what differentiates them from other scrapers. These observations have led to the assumption that *Prądnik scrapers* could illustrate a simplistic or ad hoc version of *Keilmesser* (Jöris 2001; 2004; Jöris/Uomini 2019; see also Weiss et al. 2018) and may have been produced by less experienced knappers (e.g. children), trying to mimic *Keilmesser* (Jöris/Uomini 2019). The data obtained during the techno-typological analysis, does not contradict these interpretations. However, if a *Prądnik scraper* resembles a *Keilmesser*, then the function should be similar, too. The conducted use-wear analysis can add information on that. Out of the analysed n = 23 artefacts, n = 17 pieces display use-wear traces. First of all, the majority of the documented traces is located along the active edge, confirming the interpretation of a tool with only a single active edge. Surprisingly, the large variety of traces documented for *Keilmesser* is not reflected in the studied *Prądnik scraper* assemblage. On the contrary, the surface modifications documented on the *Prądnik scrapers* are mainly from one use-wear type, type V. (C), a few from type I. (A) (**fig. 108**). This means for example, that with one exception, only polish could be found on the tool's surfaces. Interestingly, the use-wear category V. (C) is defined as extensive, shiny polish affecting the highest as well as the lowest topographical locations. Interpreted here as use-wear trace resulting from intense use. With this information, the results can now be set against the previously mentioned assumptions. To begin with, it is difficult to argue, that *Prądnik scrapers* should have the same or a similar function than *Keilmesser*. The documented traces indicate at least less versatility as the results for *Keilmesser* indicate. The question is, whether *Prądnik scrapers* would have been produced spontaneously or *ad hoc*, maybe as a reaction to a problem, or in order to learn the tool production. Would that be a tool used for such a long duration, so that use-wear traces as documented on the analysed tools can develop? The generalisation of the results is limited by the comparably small sample size and should thus not be overvalued, but the data suggests that *Prądnik scrapers* could be a simplistic version of *Keilmesser*. Simplistic in the sense of sharing the same morphological traits, which can be summarised under the umbrella term *Keilmesser* concept, but with less complex manufacturing und curation processes. The abbreviated production sequence for *Prądnik scrapers* (e.g. unifacial retouch compared to bifacial retouch) led probably to a less sophisticated active edge without the aspect of bi-functionality. Although the bipartite morphology is clearly given due to the application of the *Prądnik method*, the results of the use-wear analysis do not support a diverging use of the edge. Moreover, the results of the edge angle analysis also seem to contradict this idea to some degree. The calculated edge angle values for the *Prądnik scrapers* result in lower and therefore more acute edge angles along their active edges. One example is a *Prądnik scraper* from Ramioul. The tool, R-010, is a *Prądnik scraper* manufactured from a flake (**fig. 162**). The active edge is characterised by a unifacial retouch and one distinct *Prądnik spall* scar. This tool has an edge angle of 41.4° in the distal area where also the negative of the *Prądnik spall* removal is located (»best-fit« procedure; mean value of section two to four and distance three to six). In the proximal tool area, the active edge has an arithmetic mean value of 46.4°. This example illustrates that the active edge of *Prądnik scrapers* is slightly more acute compared to the majority of *Keilmesser*. Furthermore, the edge angle values in the proximal part are also lower in comparison. A decrease in acuteness along the active edge towards the proximal tool area is documented for the *Prądnik scrapers,* but this shift is considerably smaller, hence, the proximal tool area is barely reaching the 60°. Considering this, the mean value for the entire edge of *Prądnik scrapers* is on average 20° lower than the one for *Keilmesser*. The low edge angles might have given fewer possibilities for further retouch. At least that could explain the limited indications for retouch intensity and the absence of indications for reworking in contrast to *Keilmesser* (Jöris 2001; Jöris/Uomini 2019). In fact, a multiple application of the *Prądnik method* on *Prądnik scrapers* could only be documented three times. As demonstrated, based on the edge angle calculations, that *Prądnik scrapers* might not have a bipartite edge morphology, the assumption of a bi-functional edge is also invalid. A more plausible explanation for the edge modification with the *Prądnik method* could be seen in the aim to create a stable, straight and

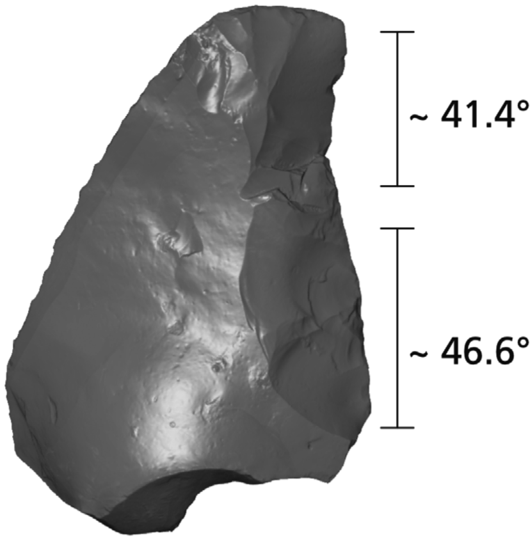


Fig. 162 3D scan of a *Prądnik scraper* (Ramioul, ID R-010) illustrating the average edge angle in the distal and proximal part of the tool (calculated with the »best-fit« procedure; mean value of section 2 to 4 and distance 3 to 6).

slightly sharper edge as suggested for *Keilmesser* as well (Jöris 2001; 2006; Frick et al. 2017; Frick/Herkert 2019; Jöris/Uomini 2019).
The analysis of the three assemblages from Buhlen, Balve and Ramioul demonstrate that *Keilmesser* are produced following a specific design. Broadly speaking, the tool concept integrates morphological attributes as the back and the base, likely used as prehensile area, the distal posterior part and the active edge. The mostly bifacially worked active edge of *Keilmesser* is characterised by a bipartite morphology or more precisely by an increase of acuteness towards the distal part of the edge. These aspects taken together form the characteristic asymmetric *Keilmesser* morphology. This morphology implies, and the results of the use-wear analysis supports the idea of *Keilmesser* as handheld and thus not hafted tools. The *Keilmesser* design, here described as *Keilmesser* concept, includes, when seen as an inclusive rather than a strict concept, also *Prądnik scrapers*. Despite the fact that *Prądnik scrapers* vary in aspects such as the blank selection and edge retouch, they are designed following the same underlying scheme as *Keilmesser* and therefore display the same morphological attributes. However, *Prądnik scrapers* seem not to have a bi-functional active edge, based on the results from the use-wear analysis and edge angle analysis. Thus, the presented data provides the idea that *Keilmesser* as well as *Prądnik scrapers* were produced according to similar tool design aspects but did not fulfil the same functional aspects. How the specific edge design of *Keilmesser* actually affects their use and if the interpretation of a multifunctional tool is supported by the results from the use-wear analysis, is discussed in one of the subsequent subchapters.

TOOL LATERALISATION AND THE IMPLICATIONS FOR HUMAN HAND PREFERENCES

Technology and use-wear to infer tool laterality

Handedness is a unique trait of humans (Uomini/Ruck 2019). As argued, handedness is closely related to brain lateralisation and cognitive evolution (Corballis/Badzakova-Trajkov/Häberling 2012; Ruck/Broadfield/Brown 2015; Cai/van der Haegen 2015; Uomini/Ruck 2018). Human behaviour related aspects such as the development of language and social learning are linked with handedness (Corballis 2003; Steele/Uomini 2008; Uomini 2009; Poza-Rey/Lozano/Arsuaga 2017; Uomini/Ruck 2019). Unfortunately, evidence for human handedness is difficult to find in the Palaeolithic record. Nevertheless, indications exist (e.g. proportions of right- and left-hand prints and stencils found on rocks and cave walls, asymmetries in fossil skeletons, striations on fossil tees; see e.g. Bermúdez de Castro/Bromage/Jalvo 1988; Trinkaus/Churchill/Ruff 1994; Frayer et al. 2010; 2012; Volpato et al. 2012; Fiore et al. 2015; Condemi et al. 2017; Frayer et al. 2016; Lozano et al. 2017), sometimes based on lithic studies (Semenov 1964; Cornford 1986; Uomini 2008; 2009; Ruck/Broadfield/Brown 2015; Jöris/Uomini 2019; Prévost/Centi/Zaidner 2020; Rodriquez et al. 2020). Although the recognition of (extinct) human hand preference is clearly limited, a bias towards right-handedness has been pointed out (Uomini 2011). Asymmetric tools such as *Keilmesser* and *Prądnik scrapers* may provide indications for human handedness. Due to their overall tool asymmetry, the tools can be distinguished in left-lateral and right-lateral tools, as demonstrated by Jöris and Uomini (2019). Thus, the tool laterality was accessed within this project. To begin with, the results from the analysis of the *Keilmesser* are addressed. In total, 79.1 % of the assemblage was defined as right-sided tools. Interestingly, in Buhlen as well as in Ramioul, the percentage of right-lateral tools is in each assemblage around 90 %. In Balve, the clear majority with 71.2 % of the *Keilmesser* were identified as right-sided artefacts and 26.2 % as left-sided artefacts. The total amount of left-lateral tools is 18.5 % of the three assemblages. The results

obtained from the *Prądnik scrapers* are similar, leading to a predominance of right lateral tools with a ratio of 81.5 % to 14.8 %. In this case, the results for the three assemblages are similar. Additionally, the *Prądnik spalls* reflect the laterality of the tools they have been removed from. The predominating right-sidedness of the *Keilmesser* and *Prądnik scrapers* is also illustrated by the *Prądnik spalls.* 61.2 % of the pieces are right-lateral, 25.8 % are left-lateral.
Taking the results of this analysis as a proxy for human handedness would indicate a clear predominance of right-handedness based on the studied assemblages. However, it should be pointed out again that the studied artefacts from Buhlen do not reflect the entire assemblage from the site. In particular the selected *Prądnik spalls* only display a small sample (n = 42 here studied *Prądnik spalls* out of 1661 existing *Prądnik spalls*; see Jöris 2001). Thus, the obtained results differ from the results published by Jöris (2001; Jöris / Uomini 2019). Having this as a constraint, further interpretation of the results would have no impact. Nevertheless, the results from the two other sites, Balve and Ramioul, do not contradict the observations made for the Palaeolithic record. As mentioned earlier, handedness may be influenced through social learning (Bradshaw / Nettleton 1982; Steele / Uomini 2009; Uomini 2009; Jöris / Uomini 2019). In this context, the standardised tool design of *Keilmesser* has been argued to be a result of continuous transmission as a skill passed on from generation to generation, as mentioned earlier (Jöris / Uomini 2019). This topic can be addressed further, and the implications of the results can be discussed in detail, but this is beyond the topic of this project. Nevertheless, based on the conducted use-wear analyses, an attempt was done to further investigate tool laterality based on the directionality of the use-wear traces.
The idea to investigate tool lateralisation based on qualitative use-wear analyses is not new (Semenov 1970), but has rarely been applied. A recent study on use-wear directionality is based on an experimental data set (Rodriguez et al. 2020). To current knowledge, tool laterality has not been linked with quantitative use-wear yet. Within this project, a first effort was done. To start with, the results of the qualitative use-wear analysis should be explained. Unfortunately, only a minority of documented use-wear traces displays a clear directionality. However, none of these traces is located in a way that indications about the directionality and thus the tool handling (in which hand the tool was hold) could be given. The results for all analysed tools suggested the slight predominance of use-wear traces along the active edge on the ventral tool surface. This general observation is similar for the n = 16 qualitatively analysed *Keilmesser* defined as left-sided tools. On these artefacts, n = 14 traces have been documented on the ventral edge, n = 15 on the dorsal edge. Assuming all the use-wear would be on the dorsal tool surface, it would be likely, that the tools defined as left-sided have been used in an identical way as the right-sided tools, presumably in the right hand. Since the results are nearly identical for both surfaces and thus inconclusive, the interpreted tool laterality can be neither supported nor denied. Unfortunately, also with the additional quantitative use-wear analysis no explicit results could be achieved. In theory, parameters such as the *isotropy, anisotropy, epLsar* or *NewEpLsar* provide information about the surface texture directionality. These parameters have been calculated for the studied artefacts, leading to no significant results so far. Significant results means that no pattern could be recognised or the data could not be interpreted in a meaningful way. As already indicated, quantitative use-wear analysis has not been applied in connection to tool laterality yet and needs to be further explored in future. Thus, there is no reference collection or any comparable data, which would help to usefully access the obtained data.

RESHARPENING AND RECYCLING BEHAVIOUR

Resharpening address by a functional analysis

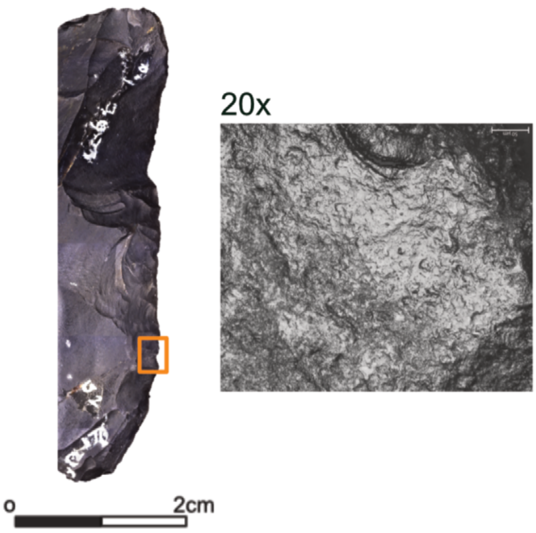
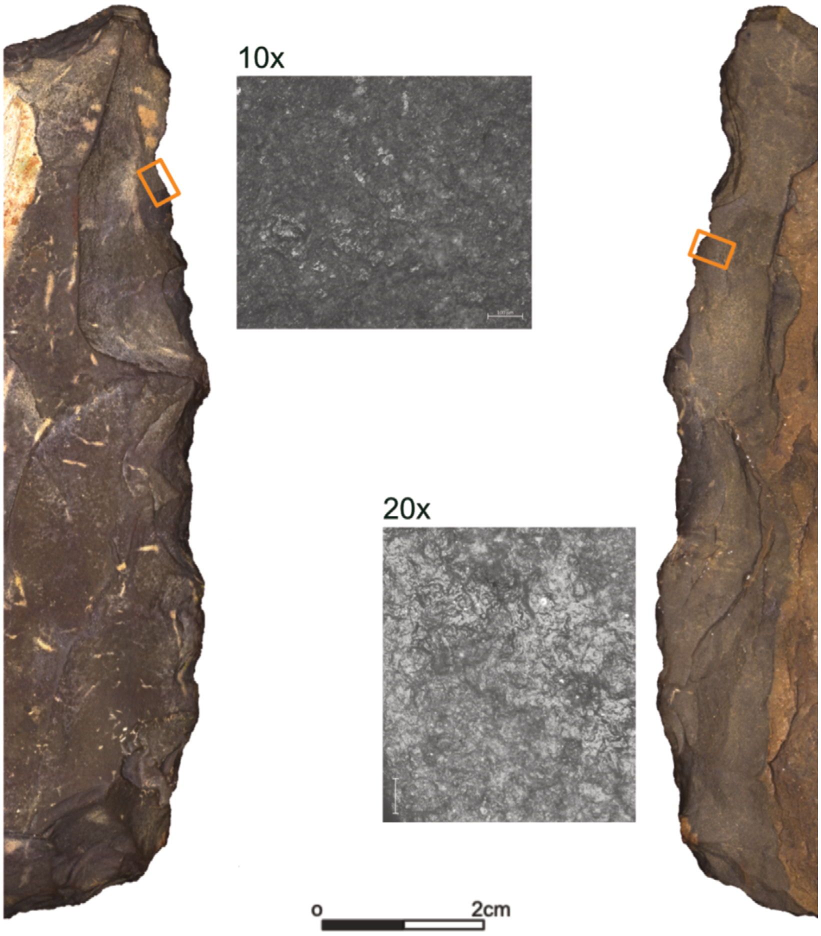


Fig. 163 EDF stitching image of the dorsal surface of a *Keilmesser* (Buhlen, ID BU-057). The image on the right shows the documented use-wear (image is taken with a 20× optical objective).

An envisaged long use-life involving the option of recurrent resharpening has been documented as an inherent part of the *Keilmesser* concept (Jöris 1994; Richter 1997; Jöris 2001; Pastoors 2001, Weiss 2020). Based on technological studies and the reconstruction of the entire *chaînes opératoire*, long usages for *Keilmesser* could be demonstrated, highlighting the presence of several phases of retouch (Jöris 2001; Frick 2016b). Within this project, resharpening has only been addressed via the documentation of the (repeated) application of the *Prądnik method*. While in total 60.8 % of the studied *Keilmesser* are modified by a *Prądnik spall* removal, only a small percentage of 12.6 % is clearly characterised by a repeated application. An additional n = 36 distal tips of *Keilmesser* are part of the analysed assemblages, interpreted as a possibility to facilitate a longer tool use by creating new striking platforms (Jöris 2001). These elements are interpreted with respect to tool transformation (*Keilmesser* tips) and as elements involved in tool finishing and resharpening (*Prądnik spalls*). One interesting aspect is the retouch intensity of *Keilmesser* made of flint compared to the ones made of lydite. Unfortunately, the flint assemblage is rather small. Nevertheless, based on the *Prądnik method* application, a first impression can be gained. Surprisingly, nearly 62 % of both, lydite and flint samples, are modified by the *Prądnik method*. A multiple application could be documented for 12.4 % of the lydite samples and for 9.1 % of the flint samples. These observations indicate a similar resharpening intensity independent from the tool's raw material. How this is reflected in use-wear, has not been discussed yet. In order to address this aspect, the results for individual artefacts are explained exemplarily for the entire assemblage. To start with, a *Keilmesser* from Buhlen, BU-057 (**fig. 163**), with a distinct scar from the *Prądnik spall* removal, displays a use-wear trace in the dorsal, proximal tool area of the active edge. This use-wear trace is defined as type V. (C), associated with relatively longer-term or intense use. The distal area of the tool, which displays the *Prądnik spall* scar, shows no use-wear traces. Moreover, the negative of the *Prądnik spall* removal gives the impression of being fresh, not least due to the lack of (intentional) retouch within this area. Taking this information together, the artefact BU-057 might represent a *Keilmesser* that was eventually modified with the *Prądnik method*. Before this, the tool has likely being used. Simultaneously, this example can be seen as an argument against the idea of the *Prądnik method* application as a tool finishing method, otherwise the scar should also display use-wear traces similar to the proximal tool part. A *Keilmesser* from Balve with the ID MU-202 (**fig. 164**) illustrates another situation. The tool displays use-wear traces along the active edge within the area of the *Prądnik spall* negative. The use-wear is categorised as type II. (B), a low-intense use-wear trace. Additionally, the same tool shows use-wear traces on the ventral surface at a comparable location to the previously described use-wear spot. These traces, however, are defined as type V. (C), a more intense use-wear. It could be argued that the tool was used and eventually, the *Prądnik spall* was removed. Hence, the less intense use-wear traces on the dorsal surface could be explained in comparison to the traces on the ventral surface. Another example is a *Keilmesser*, BU-051, with a clear *Prądnik spall* negative extending almost over the entire length of the active edge (**fig. 165**). This scar appears as rela-

Fig. 164 EDF stitching image of the dorsal (left) and ventral (right) surfaces of a *Keilmesser* (Balve, ID MU-202). The images in the middle show the documented use-wear (images are taken with a10× and 20× optical objective).



tively fresh too, despite some minimal retouch along the edge. Nevertheless, the tool displays a use-wear trace of type I. (A) near the active edge in the area of the *Prądnik spall* negative. This use-wear category is interpreted as resulting from non-intense use. Thus BU-051 probably illustrates a tool, that was finished or (re-)sharpened and used short-term or with little intensity thereafter, resulting in minor, unintentional retouch and use-wear along the edge.

Not only can the tools help when assessing the intentionality of the *Prądnik method* application, but also the removed *Prądnik spalls* themselves. A qualitative use-wear analysis has been performed for a total of n = 39 *Prądnik spalls.* This analysis resulted in the documentation of use-wear traces on n = 27 artefacts. Beneath these spalls are n = 14 primary *Prądnik spalls* displaying use-wear traces. One example is an artefact from Buhlen with the ID BU-

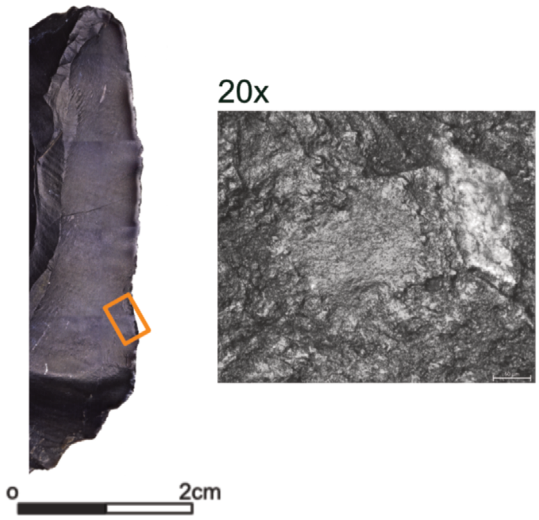


Fig. 165 EDF stitching image of the dorsal surface of a *Keilmesser* (Buhlen, ID BU-051). The image on the right shows the documented use-wear (image is taken with a 20× optical objective).

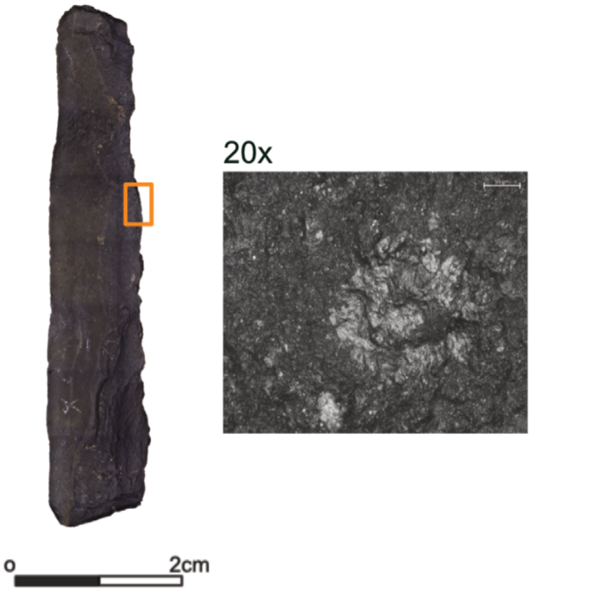


Fig. 166 EDF stitching image of a primary *Prądnik spall* (Buhlen, ID BU-129). The image on the right shows the documented use-wear (image is taken with a 20× optical objective).

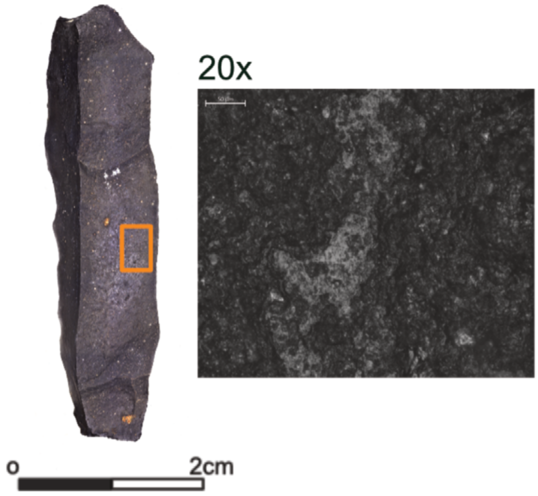


Fig. 167 EDF stitching image of the ventral surface of a primary *Prądnik spall* (Buhlen, ID MU-104). The image on the right shows the documented use-wear (image is taken with a 20× optical objective).

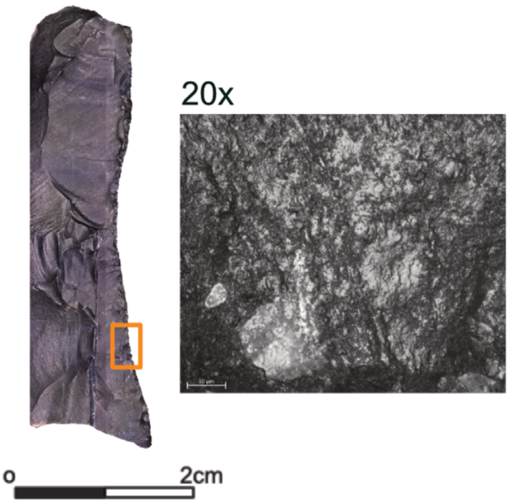


Fig. 168 EDF stitching image of a secondary *Prądnik spall* (Buhlen, ID BU-136). The image on the right shows the documented use-wear (image is taken with a 20× optical objective).

129 (**fig. 166**). On this *Prądnik spall*, a use-wear trace defined as type I. (A) could be documented. This indicates a use of the *Prądnik spall* before it was removed from the tool. However, this interpretation should be given with some caution. The majority of the documented use-wear traces on *Prądnik spalls* is not documented on the former active edge, but for instance on the ventral surface of the spall. This surface of the *Prądnik spall* was before the removal from the *Keilmesser* or *Prądnik scraper* attached to the tool and by no means could this surface have been exposed to use. One example is a primary *Prądnik spall* from Balve, MU-104 (**fig. 167**). This artefact shows intense use-wear of type V. (C) / VI. (D). Additionally, on n = 13 secondary *Prądnik spalls* use-wear could be documented. Only six of them show use-wear along the former active edge, so that the use could result from before the removal of the spall from the *Keilmesser* or *Prądnik scraper*. One example is a *Prądnik spall* from Buhlen with the ID BU-136 (**fig. 168**). The artefact shows use-wear defined as type V. (C). Findings as these support the interpretation of the *Prądnik method* as a technological option to sharpen and refresh the tool's edge.

The existence of use-wear traces on other locations besides the former active edge does not exclude the idea of reflecting the use of the *Keilmesser* or *Prądnik scraper* before the *Prądnik spall* was removed. However, the data also provides the idea that *Prądnik spalls* have been used as tools in their own right after having been produced. Interestingly, *Prądnik spalls* do reflect a comparatively high variability in the documented use-wear types, but this variability is shown on the ventral surface and not on the former active edge. The calculated edge angle values for *Prądnik spalls* (measured on the former active edge) could explain why they are likely to have been used as independent tools. The measured edge angles are significantly lower than for all other sampled and analysed artefact categories. The values range between 20° and 25°. Thus, *Prądnik spalls* do have acute edges comparable to modern razor plates. It is not difficult to imagine that *Prądnik spalls* could have been used for tasks other than those performed by *Keilmesser* or scrapers for instance.

RAW MATERIAL PROPERTIES AND THEIR IMPLICATIONS FOR TOOL PERFORMANCE

Material loss, tool damage and blunting

In this study, the large majority of the lithics are made of silicified schist, the minority of flint. The properties of these two raw materials differ to some extent. The raw material hardness and the surface roughness have been the focus of the study. Based on the analysis of the two mentioned properties, flint can be pointed out as the harder raw material (according to the Leeb rebound hardness measured with the probe C). In addition, the surface roughness of flint is lower. Not only due to the lower hardness, but especially due to the schistosity planes, the banding or the natural cracks, lydite appears as the more brittle and fragile raw material. However, in the studied archaeological assemblages, lydite has been used more often for the tool production than flint. One reason for that is unequivocally the local occurrence of the raw material near the sites. In the course of the three conducted experiments, another potential reason might has evolved. The raw material properties, as studies on Pleistocene stone tool use have long argued, influence the way the tools perform during their use. As seen on the analysed standard samples, the effect that use has on these samples differs slightly for the samples made of flint and lydite respectively. In most cases, the damage on flint samples was, especially concerning acute edge angles (e. g. 40°) smaller, and the breaking pattern was visually often similar to retouch. Thus, the flint samples were less often affected by a change or increase of the edge angle. By contrast, the lydite samples experienced alteration in the sense of material loss. Especially during cutting, samples with acute edge angles were more often affected by alteration. The material loss on the lydite samples can be described as microfracturing and small breakages. These alterations do affect the tool performance to some extent, but rarely tool functionality. At the same time, tool performance based solely on efficiency and measured on the achieved penetration depth *per* tool (material displacement), was better for lydite samples.

Interestingly, the data suggests that the raw material effects tool performance and maybe human recycling behaviour too. An important aspect thereby is the tool sharpness. Sharpness has rarely been addressed on Palaeolithic tool studies (Key 2016; Key/Fisch/Eren 2018). However, studies focusing on the sharpness of metal knives point out the influence that sharpness has on aspects such as grip force, durability (McGorry/Dowd/Dempsey 2003), the contact material and the force needed to perform a task (Schuldt et al. 2013; 2016). According to Key, Fisch and Eren (2018) sharpness can be tested by the measurement of force, material displacement and work combined with the tool performance. Two aspects might be relevant in order to measure sharpness. These are the tool edge angle as well as the tip radius (Atkins 2009; McCarthy/Annaidh/Gilchrist 2010; Schuldt et al. 2013). These thoughts are important when considering the results of the experiments. As described before, the lydite samples experienced more alteration in the sense of microfracturing. Meaning, during the experiments, when the contact between the lydite sample and the contact material was given, alteration occurred. This likely caused constant »self-refreshing«. The flint samples, however, did not alter significantly. What likely happens is that the use of the flint samples

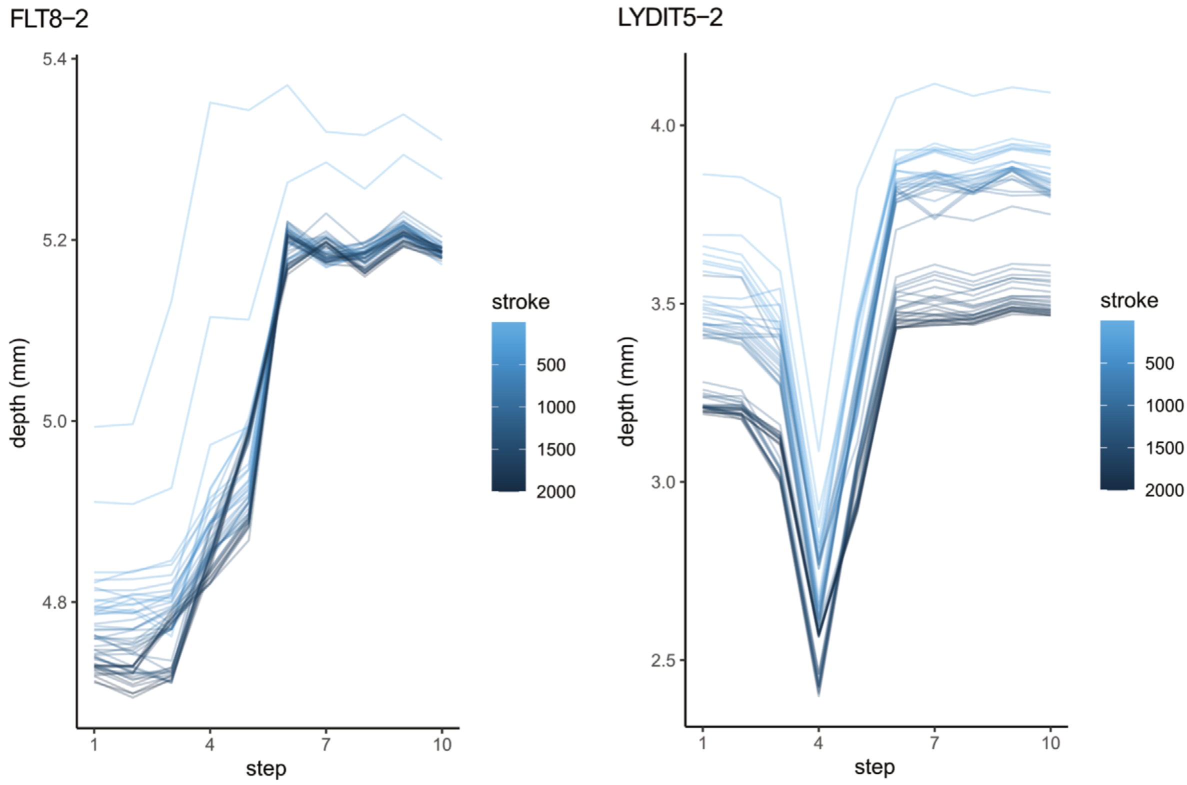


Fig. 169 Sensor recorded penetration depth achieved with a cutting movement with the SMARTTESTER® during the tool function experiment. On the left is the recording of the sample FLT8-2 and on the right the recording of the sample LYDIT5-2. The graphs show each 40th cutting stroke within all cycles (0 to 2000 strokes). The darker the colour, the more increased the penetration depth.

causes blunting through abrasion, finally resulting in a smoothening. This would explain why the lydite samples were more efficient in the sense of material displacement, as they were rather »refreshed« than smoothened. Early stage blunting can be counteracted by increasing force. Force is clearly an aspect influencing tool performance. During the experiments, force could be excluded as a relevant variable, because it was set and standardised during the experiments. Nevertheless, this means, in order to achieve the same penetration depth with flint as with lydite, the application of more force would have been needed. Due to its more fragile material properties, lydite seems to overcome the effect of early blunting by the loss of small fragments, which keeps the edge sharp to a certain degree. Experimental research on edge blunting with a variety of chert samples demonstrated that already one abrasive cutting stroke has to be compensated by 38 % increase if force and 70 % increase in work in order to achieve identical performance results (Key 2016; Key/Fisch/Eren 2018). These observation are also supported by the analysis of the penetration depth, which was sensor recorded in the course of the conducted experiments here. When looking at the results in detail, it is possible to see differences between the results obtained with the lydite and the flint samples. As an example, the samples FLT8-2 and LYDIT5-2 can be mentioned. Both samples are 45° samples used for cutting on a bone plate during the tool function experiment. The flint sample gives the impression of a continuous increase of the penetration depth during the first 100 to 150 cutting strokes (**fig. 169**). After that, the increase is only minimal. The lydite sample, however, also displays a rapid increase in penetration depth from the first stroke onwards. Moreover, the increase seems to occur stepwise. Whenever the material displacement during the cutting seems only negligible, a few strokes later, the sample penetrated deeper again. This observation demonstrates a likely correlation between the documented microfracturing of the lydite samples and the inherent »self-refreshing« properties of the raw material through microfracturing.

Which implications do these results have for the interpretations of the archaeological record? The results presented indicate that the raw material properties of lydite, which at first appearance only seem to have negative consequences for the tool use, might actually be beneficial during tool use. In order to perform a task with a tool made of silicified schist, less force and thus less work needs to be applied compared to performance with a flint tool. Of course, there might be a threshold of how much force lydite can tolerate before breaking. This threshold is likely higher for flint due to its elevated hardness values. However, there is also a limit of how much force can be applied by a human hand. These aspects are out of the scope of the study presented and discussed here, and therefore, in future, they need to be experimentally investigated further.

TOOL-USE AND FUNCTIONALITY

The multifunctional aspect of *Keilmesser*

Based on the design of the active edge and the general tool morphology, *Keilmesser* are commonly interpreted as tools with a singular bi- or multifunctional active edge (Jöris 2001, Urbanowski 2003; Jöris 2006; Rots 2009; Jöris 2012; 2014; Golovanova et al. 2017; Frick / Herkert 2019; Frick 2020b). The conducted use-wear analysis could clearly indicate that the main focus during tool use is on the active edge. The majority of the use-wear traces could be documented along the active edge. With 77.4 % of the traces, this result is unambiguous. The documented traces slightly prevail on the ventral than on the dorsal surface.
Concerning the functionality of the tools, the answer to the question is more complex. In order to assess the topic, the interpretation of the documented use-wear types should be discussed first. As mentioned in the previous chapter, the qualitative use-wear analysis performed within this project does not aim at a functional interpretation and the identification of the contact material. The reason for that is mainly given by the lack of a reliable reference collection for use-wear traces on silicified schist. Nevertheless, some aspects concerning the intensity of the traces and their implications can be discussed. First of all, the defined categories of use-wear traces can be separated into two main features: polish and striations (the latter which may appear in tandem together with polish). Within these categories, there are noticeable intensity nuances (**fig. 103**; **tab. 37**). Polish as use-wear is defined by the categories I. to V. While category I. (A) describes small spots of polish, which are only slightly abrasive and only effect the highest topography, category V. (C) is extensive polish affecting the lowest as well as the highest topographical levels. The traces displaying striations (VI. – VIII.) affect all topographical levels. The analysis of the use-wear traces indicates a correlation between the intensity of the use-wear traces and the duration of the tool use. Following this interpretation, short-term or less intense use only leaves small traces on the highest topography of the surface. With increasing duration of the tool use, the traces are getting more extensive and abrasive. Measured on the abrasiveness of the traces with striations, these traces reflect also high intensity or long-term tool use. Based on this interpretation, the resulting consequences can be discussed. Following this interpretation, use-wear traces reflecting a long-term use should be predominantly located along the active edge. This is the case in this study, but at the same time, there are also such use-wear traces (e. g. category V., VI. and VII.) located on the back of the *Keilmesser*. At first glance, this sounds contradictory. Assuming that only the active edge of *Keilmesser* has been used, then traces along the back should only display traces of short-term activities, post-depositional traces or traces resulting from unintended use. However, they also display traces associated with a longer or more intense use. For example n = 20 out of n = 44 traces documented along the back of *Keilmesser* are

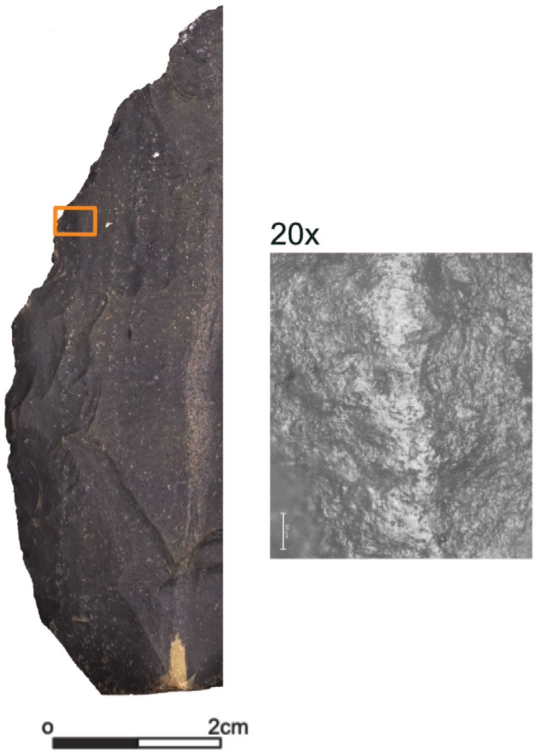
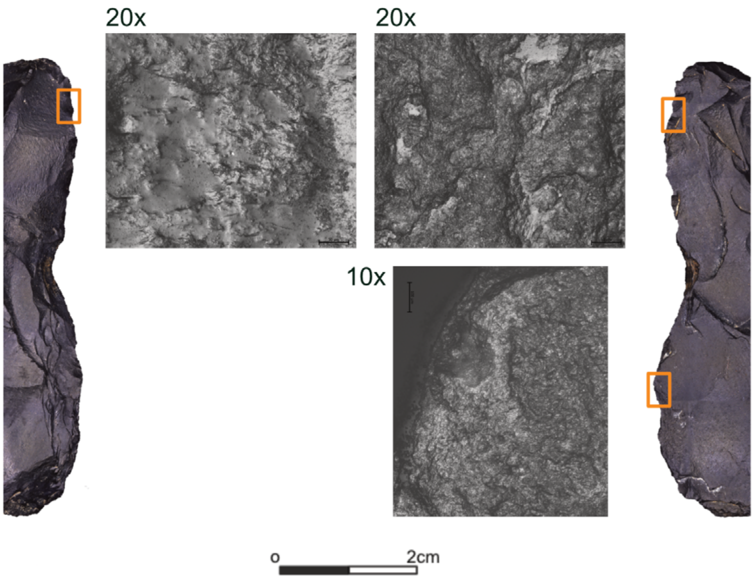


Fig. 170 EDF stitching image of a *Keilmesser* (Balve, ID MU-199). The image on the right shows the documented use-wear (image is taken with 20× optical objective).

defined as use-wear type V. (C). These n = 20 traces have been observed on in total n = 16 *Keilmesser*. Interestingly, the majority of these 16 *Keilmesser* (n = 10) are partly retouched or retouched along the edge of the back and distal posterior part (n = 4 are unworked, n = 2 are undefined) (e. g. *Keilmesser* MU-199; (**fig. 170**). These findings do not contradict the idea of *Keilmesser* as tools with one active edge. The numerously documented traces along the active edge still support this statement. However, a small amount of tools also display traces along the back associated with long-term or intense use. Most of these *Keilmesser* are retouched in the corresponding areas of the back. These results indicated that the use of *Keilmesser* might have been more versatile or the handling less static than expected.

In general, within the studied artefact categories, *Keilmesser* illustrate the highest variability of documented use-wear types. A nearly, but not comparable high variance is documented for the scrapers, which built an outgroup within the study. Further indications regarding the tool function and use are given through the distribution of the use-wear traces. Following the interpretation of *Keilmesser* as a multifunctional tool with an active edge designed for different actions, this should be reflected in the accumulation, the distribution and potentially in the type of use-wear traces along the active edge. In order to address this topic more specifically, the results of individual samples will be discussed exemplarily. Assuming a *Keilmesser* would have been used with the distal part of the tool for a different action than the proximal part of the tool. This would likely lead to diverging use-wear traces. A tool, which could have been used for these minimum two actions could be the *Keilmesser* with the ID MU-111 (**fig. 171**). The application of the *Prądnik method* is clearly visible by an elongated negative in the distal part of the active edge. This sample displays intense use-wear (type IV.) in the exact same, distal tool area. Parallel to these traces, similar use-wear can be found on the same location, but on the ventral tool surface. The use-wear on the ventral surface is of the same type, but extends less. Additionally, the tool displays use-wear traces in the proximal part of the tool on the ventral surface. This documented use-wear spot is defined as use-wear type III. and thus, categorised as a polish, too, but resulting from a less intense use. The fact that the differing use-wear traces are documented on the ventral, flat surface of the tool, makes it difficult to imagine that they could have formed simultaneously during one type of action. Assuming these traces are the result of a cutting movement, involving the entire length of the active edge, it would be difficult to explain why the traces in the distal tool area are more intense than in the proximal area although the surface is flat and even. Thus, the sample MU-111 could be an example for a *Keilmesser* with a multifunctional active edge. Moreover, there are *Keilmesser* supporting the idea of a tool with a versatile purpose. Following this interpretation does not mean that the tool was actually used for all possible purposes, but that it was in general designed to perform varying tasks. Consequently, there are *Keilmesser* displaying traces either only in the distal, the medial or in the proximal area of the active edge. *Keilmesser* MU-246 is such an example (**fig. 172**). Intense polish (type V. / VI.) was documented in the distal

Fig. 171 EDF stitching image of a *Keilmesser* (Balve, ID MU-111). The images in the middle show the documented use-wear (images are taken with 20× optical objective).



part of the tool on the dorsal as well as the ventral surface. The quantitative use-wear analysis results in an arithmetic mean value of 1.5 µm for *Sq*, expressing the root mean squared height, and thus reflecting the micro surface roughness. A *Sq* value of 1.5 µm in the context of the studied material is comparably small and thus supports the interpretation of a surface modification affecting the highest and the lowest surface topographies as described for the use-wear types V. and VI. Despite this intense polish in the distal part of the tool, no further use-wear traces could be documented. Based on these observations, it seems likely, that the tool was only used in the distal tool area and not with the entire length of the active edge. Here, a correlation with the location of the traces and the tool handling seems likely. The *Keilmesser* illustrates no indications for a tool hafting and is a comparably small tool with 5.4 cm in average length. A tool handling

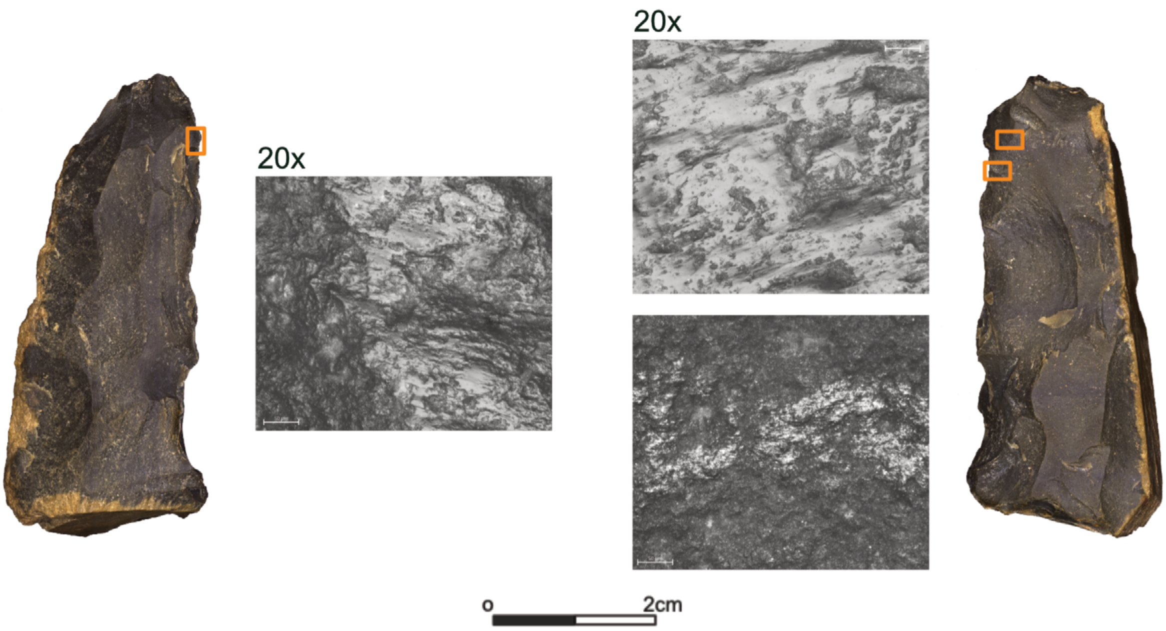


Fig. 172 EDF stitching image of a *Keilmesser* (Balve, ID MU-246). The images in the middle show the documented use-wear (images are taken with a 20× optical objective).

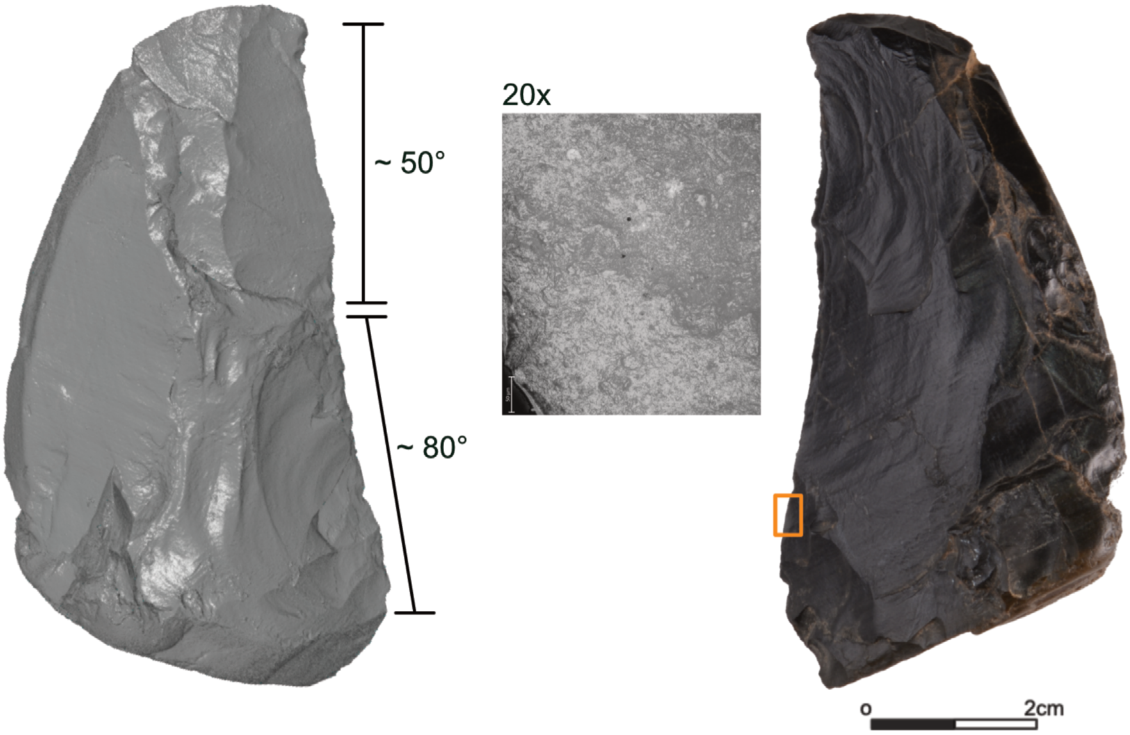


Fig. 173 3D scan (left) and EDF stitching image (right) of a *Keilmesser* (Buhlen, ID BU-158). The image in the middle shows the documented use-wear (image is taken with a 20× optical objective). The 3D scan indicates the average edge angle in the distal and proximal part of the tool (calculated with the »best-fit« procedure, mean value of section 2 to 9 at the 3 mm to 6 mm distance to the intersection).

as suggested by Frick et al. (2017) or Jöris and Uomini (2019) for a carving movement could explain the absence of use-wear traces in areas other than the distal tool part. According to these descriptions, the index finger (Frick et al. 2017) or the thumb (Jöris/Uomini 2019) is pressing against the back of the tool, while the other fingers embrace the base and thus the proximal part of the tool. Following this interpretation, only the distal tool area would be exposed to use. At the same time, there are tools within the studied material, which are characterised by the absence of traces in the distal part of the tool, while the proximal part of the tool displays traces. One example is the *Keilmesser* with the ID BU-158 (**fig. 173**). Use-wear type V. could be documented on the ventral surface of the *Keilmesser*. The tool is modified by a removal of a *Prądnik spall* on the dorsal surface. The changing character or quality of the active edge from the distal to the proximal tool area is also expressed by the edge angle values. The average edge angle for the upper part of the tool is 50°, the mean value for the lower, proximal part is 80° (»best-fit« procedure, mean value of section two to nine at the 3 mm to 6 mm distance to the intersection). In general, as previously explained, edge angles below 60° are seen as acute edge angles suitable for tasks such as cutting. Edge angles above 60° are too blunt for cutting and therefore more suitable for carving and scraping tasks (Veil et al. 1994; Weiss 2020). This observation separates the active edge of the described *Keilmesser* into two morpho-functional parts. Taking all these aspects together, the interpretation of the tool only used with the proximal part for instance for a scraping or carving movement cannot be denied. At least, only there, the use led to the formation of use-wear traces. Contrary to these examples, there are also tools displaying identical use-wear traces along the entire active edge. One example is the *Keilmesser* MU-214 (**fig. 174**). On the ventral surface of the tool, three spots of use-wear, categorised as use-wear type V. (C), could be documented. The dorsal surface does not display use-wear traces. Interestingly, this *Keilmesser* is characterised by the application of the *Prądnik*

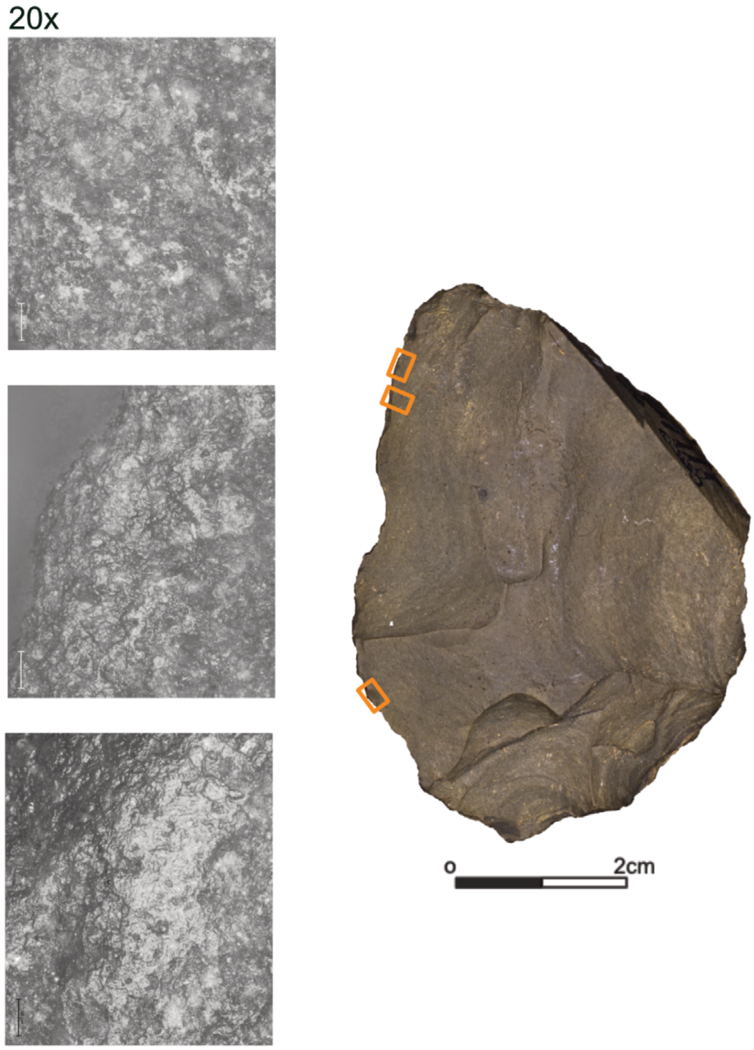


Fig. 174 EDF stitching image of the ventral surface of a *Keilmesser* (Balve, ID MU-214). The images on the left show the documented use-wear (images are taken with 20× optical objective).

method, but represents one of a few exceptions with a negative of the *Prądnik method* on the ventral surface. Therefore, the documented use-wear traces on the ventral surface are located in the negative left by the removal of the *Prądnik spall* and below in the proximal tool area. Based on the documented use-wear traces solely, this *Keilmesser* offers no indication for versatile use. Here, the question needs to be raised, what tool multifunctionality implies? Assuming multifunctionality describes a tool, designed in a way that several (or at least two) tasks could be potentially performed in a useful way. If only the aspect concerning the design is of relevance, then it is not important, whether the tool was actually used for multiple purposes or not. Considering this, the results of the presented examples, which are in place of all studied *Keilmesser*, are in line with the interpretation of *Keilmesser* as multifunctional tools (Jöris 2001; 2006; Rots 2009; Jöris 2012; 2014; Golovanova et al. 2017; Frick/Herkert 2019). Generally speaking, the results from the qualitative use-wear analysis indicate that *Keilmesser* illustrate tools with a versatile application. Derived from the distribution of the use-wear traces and types, an identical handling and use for all tools is inconceivable. As described, the idea concerning a versatile tool functionality is supported by the edge angle calculation. However, it is not imperative, that all *Keilmesser* were used for multiple purposes. Based on the results from the use-wear analysis solely, it seems as if most of the *Keilmesser* do reflect traces resulting from a single activity only.

Tool use in site context

With the just discussed results in mind, it should be mentioned again, that the results from the use-wear analysis performed on the *Keilmesser* from Buhlen led to a slightly diverging picture. In general, as explained, from Balve and Ramioul, *Keilmesser* do reflect a variety of use-wear types. However, the analysed *Keilmesser* from Buhlen differ in this aspect (**fig. 105**). In this sample, mainly use-wear traces from the category I. (A) and V. (C) could be documented. This observation raises the question, whether *Keilmesser* from Buhlen were used for different purposes than in Balve and Ramioul? Based on the identified use-wear types, it is clear that no striations could be documented along the active edge, narrowing the base for arguments for a multifunctional from a use-wear point of view. In order to answer this question fully, additional artefact categories from the site need to be analysed. This would allow to investigate the aspect, whether *Keilmesser* in Buhlen have not been used as multifunctional tools, but instead, for a specific purpose. Nevertheless, the *Keilmesser* from Buhlen do display less (I.) as well as more intense use-wear (V.). The use-wear of type V. is thus also often located along the active edge in the distal area of the tool. The quantity of lateral *Prądnik spalls* in Buhlen is extremely high, outnumbering the quantity of *Keilmesser* and *Prądnik scrapers* (Jöris 2001). If it would be the case that mainly use-wear traces resulting from short-term or low intense use are reflected in the distal tool area, then it can be advocated that the tools were likely frequently resharpened. However, the intense use-wear traces in this tool area make it difficult to argue, and different use of the *Keilmesser* from Buhlen compared to Balve and Ramioul is thus unlikely. Nevertheless and interestingly enough, the *Keilmesser* from Buhlen reflect less striations, limiting the arguments for a multifunctional tool use.

Tool performance and variables affecting it

In order to access tool use and function for the studied asymmetric tools further, the results of the conducted controlled experiments should be include and discussed. Before delving into the results, the overarching goal of the experiments should be stressed again. The individually conducted, *second-generation experiments* aimed at identifying the influence of certain independent variables within the chosen experimental settings. Within the three experiments, the tested independent variables were raw material, edge angle, contact material as well as movement. It should be pointed out, that the goal was not to produce a use-wear reference collection for a comparison with the archaeological record. Instead, the influence of each mentioned independent variable on tool performance should be explored. At the same time, the experiments were meant to document the formation and the development of use-wear traces under controlled conditions. In this context, the mechanics behind the use-wear formation should be questioned based on the results of the quantitative use-wear analysis. The results concerning the differences in tool performance, depending on the raw material of the standard sample, measured on the penetration depth and the tool alteration (edge angle change) have been shortly addressed in the previous subchapter. Thus, this topic is not dealt with here again. Instead, the result from the tool function experiment regarding the edge angle and the movement should be mentioned. First of all, it has to be noticed that independent from the raw material and the edge angle of the sample, both tasks – cutting and carving – could be performed without the standard samples losing functionality. Since the edge angles have been extrapolated from the 3D models of the analysed *Keilmesser*, with reservation, the data can be transferred to the archaeological record. Meaning, the design of the average *Keilmesser* active edge should allow in theory for movements such as cutting and carving. Based on common interpretations, also scraping is assumed as a possible function of *Keilmesser* (Frick et al. 2017; Jöris/Uomini 2019) and should therefore be tested in future experiments.

The evaluation of the results from the qualitative use-wear analysis indicated that cutting more easily leads to the development of use-wear traces. The penetration depth into the contact material can likely explain this observation. During cutting, the standard samples went deeper into the contact material, increasing the area of contact between the standard sample and the contact material. During carving, the penetration depth was lower and the contact zone smaller. Thus, the developed use-wear on the standard samples used for carving is only marginal. Interestingly, the quantitative data obtained from the standard samples used during the experiment led to no identifiable differences regarding the movement. Meaning, based on these quantitative results only, the performed movement could not be identified. However, more relevant than the movement from the quantitative point of view proved to be the edge angle. The quantitative data correlated with the information about the edge angle of the samples formed distinct data clusters (**fig. 156**).

Surface texture roughness and the formation of use-wear traces

In the context of the experiments, the results from the quantitative use-wear analysis should be elaborated a bit further. In order to access the influence of the tested independent variables, the calculated (ISO) parameters should be mentioned. Each of the measured 34 parameter can potentially give some indications concerning a surface variation. Within these parameters, *Sq* (surface texture roughness) appeared as a prominent parameter. This is not only reasoned in the fact that quantitative use-wear studies most often refer to areal field parameters such as the amplitude parameters (e.g. *Sq, Ssk, Sa*) (Martisius et al. 2020; Pedergnana et al. 2020b), leading to a slightly better understanding of this parameter, but also due to the clear indications the data provides. When referring to the »artificial VS. natural« experiment, the results gained through the use of the four different contact materials are revealing. Before going into detail, it should be noted again that the measured *Sq* values for the standard samples made of flint, resulted in a lower micro-surface roughness than the lydite samples. Eight of the standard samples used during the »artificial VS. natural« experiment have been quantitatively analysed before and after (2000 strokes) the experiment. The results of this quantitative use-wear analysis provide a new insight into the relationship between the original surface texture roughness of the tools and the development of use-wear traces on that surface. The standard samples with an initial low surface texture roughness (mainly the flint samples) did not change significantly in the course of the experiment (**fig. 142**). Standard samples with an original rougher surface resulted in a modified surfaces roughness with a tendency of increasing values. In other words, a rough surface gets rougher after intensive use. The data indicates that a surface with a high surface texture roughness is more prone to abrasion processes than a low surface roughness. These findings are in line with the interpretation of polish formation as a result of abrasion processes (Schmidt et al. 2020). Within the conducted experiments, the surface texture of the raw material seems thereby of more relevance than the properties of the contact material. While these observations are important to understand the mechanics behind the formation of use-wear, they can also be transferred to some extent to the archaeological record. In order to explain this, one example is given. The example is a *Keilmesser* from Balve with the ID MU-224 (**fig. 175**). Use-wear traces could be documented in the distal part of the tool on the dorsal as well as on the ventral surface. While the use-wear trace on the dorsal surface is defined as type III. (B2), the use-wear trace on the ventral surfaces is categorised as type V. (C). Both use-wear traces have been analysed quantitatively. Since both spots are documented on the same tool, the initial surface texture roughness of this flint sample can be assumed as identical on both surfaces. Although the visual difference between the two use-wear traces is not extreme, the results indicate a diverging surface texture roughness. The calculated *Sq* value for the spot of type III. is 1.33 µm and for the other spot, type V., is 1.49 µm. This data supports the interpreta-

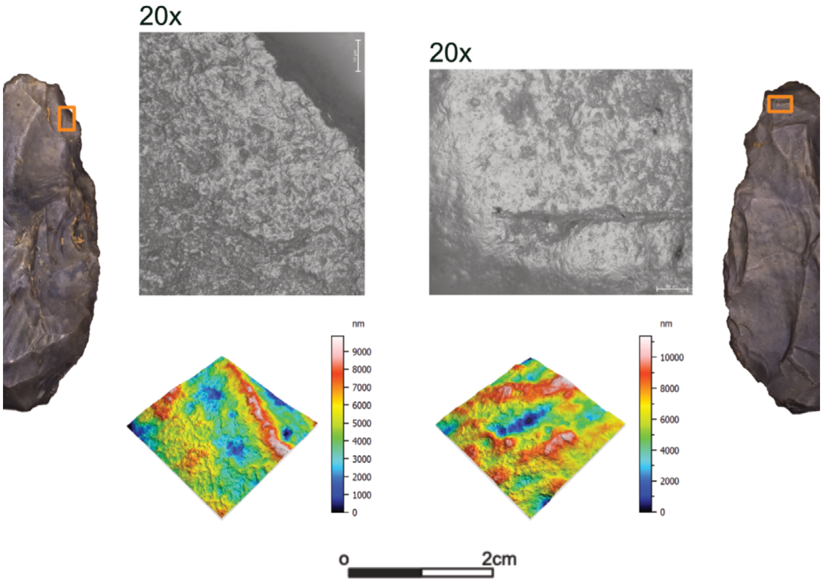


Fig. 175 EDF stitching images of the dorsal (left) and ventral right surfaces of a *Keilmesser* (Balve, ID MU-224). The images in the middle show the documented use-wear (images are taken with 20× optical objective) and the corresponding micro-surface texture. The colour of the surfaces corresponds to the height on the z-axis.

tion of the defined use-wear traces as a main result of varying use duration and/ or intensity. Moreover, this implies another aspect: *Sq*, when combined with the original surface texture roughness, can likely serve as an indicator for the duration or the intensity of the tool use. In order to underline this theory, the quantitative data from the archaeological samples was plotted together with the data from the standard samples (**fig. 176**). All plots can be found on GitHub in the corresponding repository [https://github.com/lschunk/use_wear-archaeology_meets_experiment]. The boxplots show the archaeological data separated in the use-wear types and with the artefact categories highlighted in different colours. Additionally, the data from the standard samples are included in the plot separated as before and after 2000 strokes. When looking at the boxplot from the parameter *Sq*, the previously described observations are supported. The combined *Sq* values of all analysed standard samples tend to vary more after usage. However, it should be noted that a direct comparison is not given, since the data results on the one hand from archaeological samples and on the other hand from machine cut standard samples, but the underlying trend seems to be comparable.

Contact material and use intensity

The here mentioned observations resulting from the quantitative use-wear analysis also help to answer another question. Among others, one aim of the »artificial VS. natural« experiment was to identify whether the use of standardised contact material can be justified over the use of natural contact material measured on tool performance and the development of use-wear traces. The answer to this question needs to be given from two diverging point of views. The use of standardised contact material within an experimental setup with the goal of producing a reference collection for a comparison with archaeological samples should be only done with reservation. Although the produced use-wear traces visually resemble the traces developed through the use of natural contact material, this does not need to be the case for traces on knapped material. Within the course of the conducted experiments, only standardised samples have been used. The use of the standard samples was necessary in order to exclude certain variables. However, this aspect illustrates the limitations of *second generation experiments*. The obtained conclusions need to undergo further testing in a more realistic scenario (*third generation experiment*, see Marreiros et al. 2020) before being conclusively transferred to the archaeological record. Another answer can be given when using standardised contact

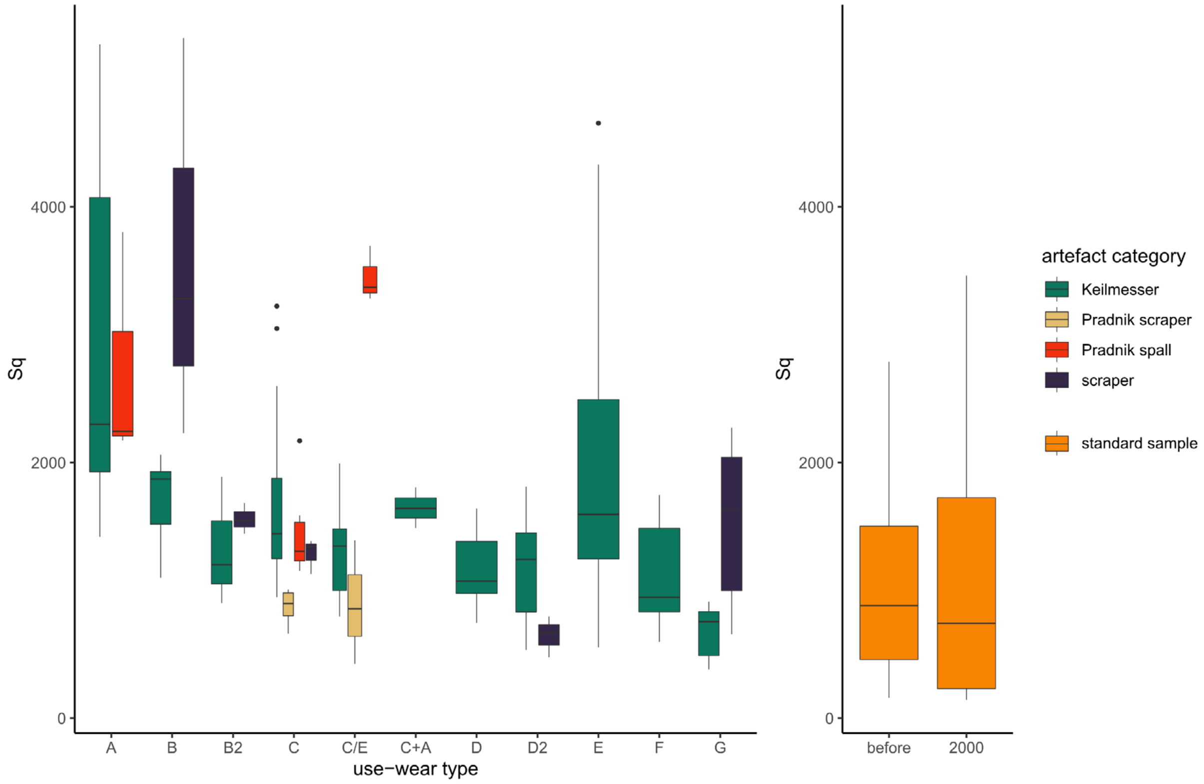


Fig. 176 Distribution of *Sq* values for the measured use-wear traces (n = 50) on the archaeological artefacts (left), combined with the measured use-wear traces (n = 28) from the »artificial VS. natural« and tool function experiment (right). The data is categorised according to the interpreted use-wear types and coloured based on the artefacts type.

material in an experimental setup, in order to investigate the influence of a specific variable within the setup. For example, here, it was the goal to investigate tool performance and the formation of use-wear traces as well as the mechanics behind both. In such a scenario, the use of standardised contact material should be compulsory. In the case of the conducted »artificial VS. natural« experiment, the use of both types of contact materials in comparison results in similar observations. One of them concerns the raw material of the standard samples. The use of natural as well as the use of artificial contact materials led to the suggestion that the correlation between the formation of use-wear traces and the raw material of the sample might be of more impact than the one between the formation of use-wear traces and the contact material. Moreover, this formation is highly correlated with the duration or the intensity of the tool use. This idea is supported by the results from the qualitative as well the quantitative use-wear analysis. All analysed standard samples (»artificial VS. natural« and tool function experiment) developed within the course of the experiments use-wear. The data taken together indicate that the use-wear formation under the tested conditions is dependent on several aspects. The order of these aspects based on their implications should likely be as follows: 1) the raw material of the sample, 2) the intensity or duration of the use, and 3) the contact material.
Within this chapter, several aspects concerning asymmetric tools such as *Keilmesser* and *Prądnik scrapers* have been discussed and interpreted within and between artefact categories. To do so, only a multidisciplinary approach allowed for testing previous interpretations regarding these tools. The chosen approach allowed for new data to be gained, providing new insights and a more distinct picture about these Late Middle Palaeolithic tools. Seen as major evidence to understand how humans produced, designed and used their tools in the past, this new information have an impact on contextualising technological behavioural choices of Neanderthals.