STATE-OF-THE-ART

MIDDLE PALAEOLITHIC ASYMMETRIC TOOLS

Archaeologists attempt to answer questions regarding the evolution of human behaviour through the study of material culture. In the Pleistocene, stone tools were essential to the survival of hominins. Hence, lithic artefacts provide insights into early hominin behaviour, through their technological adaptations and innovations (Klein 2000; Odell 2000; Ambrose 2001; Lycett 2015; Dibble 2017; Key/Proffitt/de la Torre 2020). This is conditional upon understanding the production, design, function and use of the huge variety of artefact categories in the archaeological record. In the case of Middle Palaeolithic Neanderthal's assemblages, the tool variety can be described by an occurrence of mainly hand axes, foliated pieces and several types of scrapers and points. Throughout the Middle Palaeolithic, this pattern seems consistent, leading to the impression of a certain stasis and little alteration concerning the composition of lithic assemblages (Gamble/Roebroeks 1999; Hovers/Belfer-Cohen 2006). Besides the aforementioned tools, the presence of some asymmetric tools in the Late Middle Palaeolithic became prominent in Central and Eastern European sites (Bosinski 1967, Mania/Toepfer 1973; Veil et al. 1994).

The asymmetry of these tools is due to the presence of only one single active edge opposed to a back, contrary to tools with two similar lateral edges as for instance hand axes. Tools with such an outstanding characteristic are namely *Keilmesser* – bifacial backed knives – and *Prądnik scrapers* (Krukowski 1939; Bosinski 1967; Jöris 2001; 2012). Although *Keilmesser* are occasionally found in older site contexts (e.g. Marks 2002; Solecki/Solecki 2001), the vast majority of these tools as a morphological type is associated with the Late Middle Palaeolithic of Central and Eastern Europe (Jöris 2004; 2006).

The geographical distribution of these assemblages can be roughly defined by Central and Eastern Europe (**fig. 1**). Recently, also sites in the Altay Mountains (Okladnikow Cave, Chagyrskaya Cave) (Kolobova 2020) were described as *Keilmesser* yielding assemblages, expanding the geographical distribution further east to Asia. The majority of sites are located in Central Europe. Eastern sites are located in Poland (e.g. Ciemna, Zwolén, Wylotne, Bisnik Cave) (e.g. Krukowski 1939; Burdukiewicz 2000; Urbanowski 2003; Serwatka 2014; Valde-Nowak et al. 2016) and Czech Republic (e.g. Kůlna Cave) (Neruda 2017). Well-studied German sites include for example Sesselfelsgrotte (Richter 1997; 2016; Delpiano/Uthmeier 2020), Klausennische (Mania/Toepfer 1973; Picin 2016) and Bockstein (Wetzel 1958; Bosinski 1969) in the South, Lichtenberg (Veil et al. 1994; Weiss 2020) in the North and Balver Höhle (Andree 1928; Bahnschulte 1940; Günther 1964; Wetzel/Bosinski 1969; Günther 1988) and Buhlen (Bosinski/Kulick 1973; Bosinski 1969; Jöris 2001) in Central Germany. The site of Grotte de la Verpilliere (Frick 2016a; 2016b; Frick/Floss 2017) is to mention as an example for the French region. La Grotte du Docteur (Ulrix-Closset 1975) and Ramioul (Vandebosch 1921; Ulrix-Closset 1975) in Belgium are further examples for Central European sites. The frequency of *Keilmesser* within a chronological comparably narrow time interval (late OIS 5 until mid OIS 3 (Jöris 2004; 2006) led to the introduction of the term »*Keilmessergruppen*« for such lithic assemblages (Mania 1990; Veil et al. 1994; Jöris 2004; 2006; 2012). The term was first introduced by Mania in 1990.

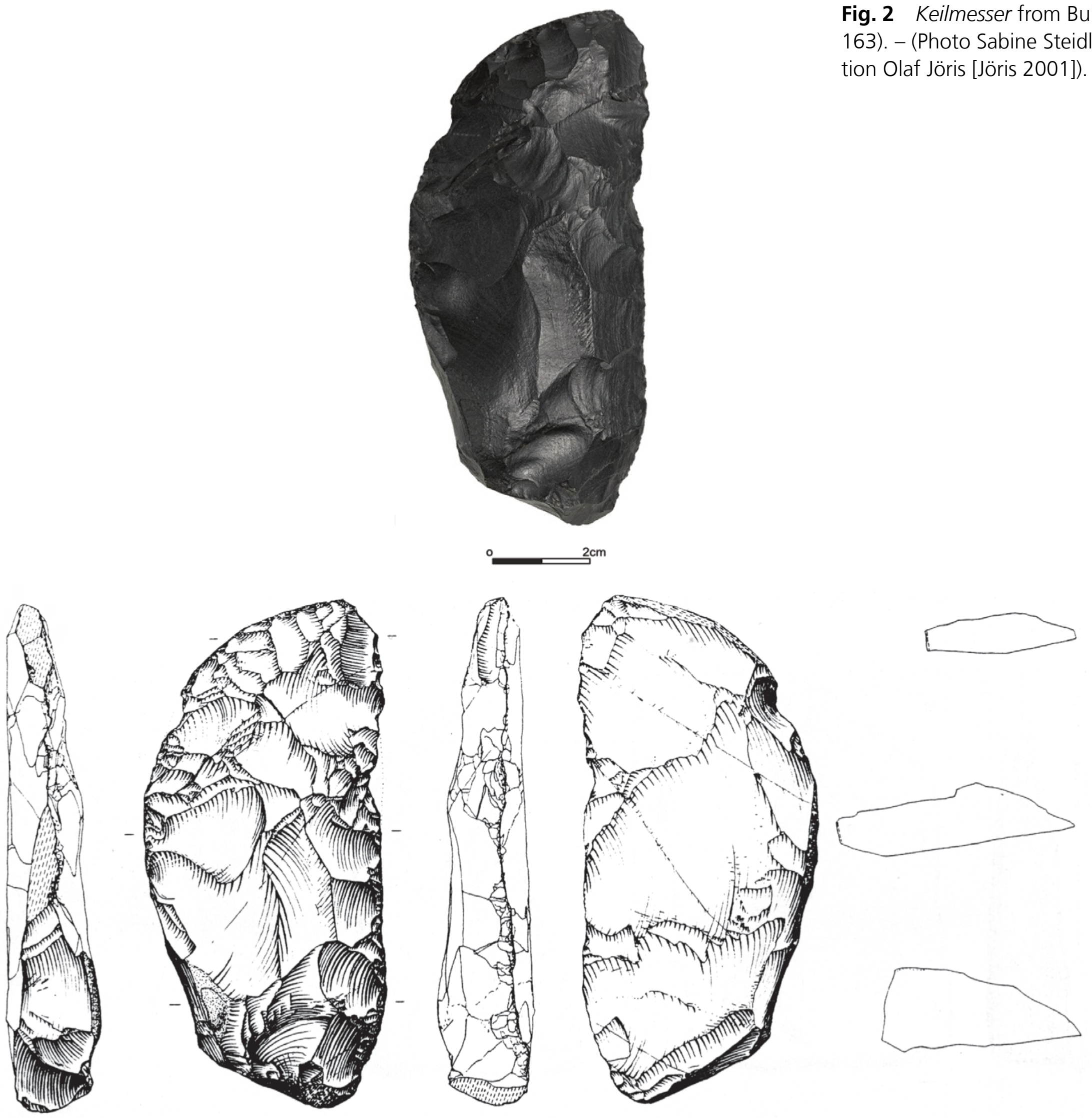

Fig. 2 *Keilmesser* from Buhlen (ID BU-163). – (Photo Sabine Steidl, RGZM; Illustration Olaf Jöris [Jöris 2001]). – Scale 2:3.

Keilmesser

Based on their morphology, *Keilmesser* display a clear asymmetric shape with a triangular or wedge-shaped cross section (Jöris 2006; 2012) (**fig. 2**). The German tool's name, *Keilmesser*, originates from this wedge-shaped section. *Keilmesser* are mainly produced as core tools and, more rarely, from flakes (Jöris 2001; Jöris / Uomini 2019). The shape characteristics of the blank chosen for the manufacture of the *Keilmesser* appear integrated into the overall tool concept (Jöris 2006; 2012; Frick / Floss 2017; Frick / Herkert 2019, Wiśniewski et al. 2020). Resulting from this specific selection, the back of a *Keilmesser* normally forms the thickest part of the tool. While the back is commonly natural or roughly worked, the active edge is mostly bifacially retouched. Additionally, *Keilmesser* usually have a flatter lower surface compared to the more strongly curved upper surface. The morphological design supports the idea of *Keilmesser* as a handheld tool (Jöris 2001; Jöris / Uomini 2019). Evidence for hafting is rare, if not absent (Rots 2009).

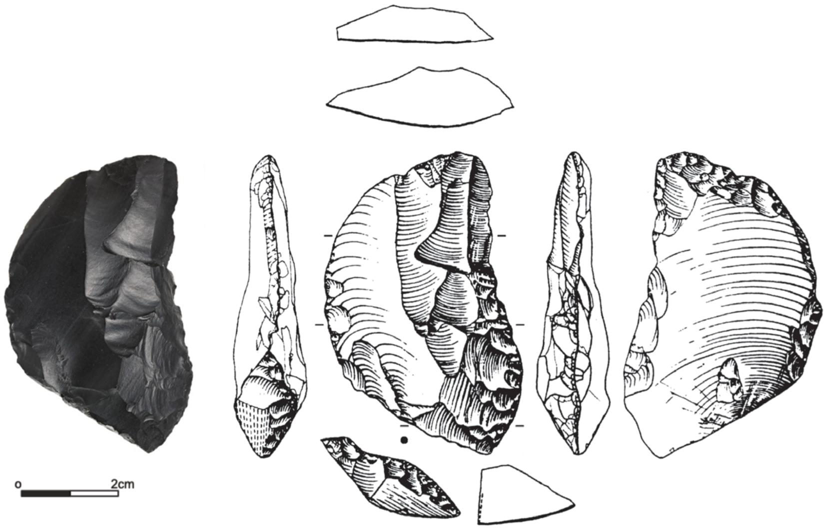

Fig. 3 *Prądnik scraper* from Buhlen (ID BU-194). – (Photo Sabine Steidl, RGZM; Illustration Olaf Jöris [Jöris 2001]). – Scale 2:3.

Prądnik scrapers

Alongside *Keilmesser*, KMG assemblages sometimes yield scrapers, the so-called *Prądnik scraper,* displaying many similarities with the previous described *Keilmesser* (Jöris 2001; 2004; Jöris/Uomini 2019) (**fig. 3**). Even though the distinction between the two artefact categories is not clear cut, a terminological differentiation is required. The scrapers are usually made from flakes, not from cores. Similar to *Keilmesser,* they have natural back, asymmetric sections and/ or clear, intentional blunting opposite the active edge. In comparison, the production of this artefact category seems to follow the same underlying tool design as for *Keilmesser*, but the entire processing sequence appears to be simplified and less complex (Jöris/Uomini 2019). This assumption might be associated with rather short tool biographies and the usual absence of indications for re-working and re-use in contrast to *Keilmesser*.

So far, *Prądnik scrapers* have rarely been an intensive focus of lithic studies. A reason for this can be found in their occurrence. *Prądnik scrapers* are not always part of *Keilmesser* assemblages. Although they can be found together with *Keilmesser,* they exist always in smaller numbers. Nevertheless, further analyses focusing more on the similarities and /or on the distinctions might provide new information about this artefact category, inevitably raising the question of how *Keilmesser* and these scrapers are related.

Prądnik method

Prądnik scrapers are always, *and Keilmesser* frequently, characterised by a special lateral tranchet blow modification on the active edge (Jöris 1992 2001; Frick et al. 2017; Frick/Herkert 2019; Frick 2020a) (**fig. 4**). This modification detaches an elongated spall running from the tool's tip along the lateral edge. Various names are known to describe the modification as for instance »*Prądnik technique*«, »*Prądnik method*« or tranchet blow (Frick et al 2017; Frick/Herkert 2019; Frick 2020a). Since the modification on *Keilmesser* and *Prądnik scrapers* is not identical to tranchet blows on other artefact categories (e.g. scraper) (Cornford 1986; Douze 2014; Zaidner/Grosman 2015; Frick et al. 2017; Frick 2020a; Prévost/Centi/Zaidner 2020), the term *Prądnik method* is given preference here. The method can be applied by one or more blows to the distal part of the tool. Depending on the state of the active edge, a certain preparation was required (e.g. previous blunting). The repeated application can be either seen on the tool itself by superimposed negatives

Fig. 4 *Keilmesser* from Balver Höhle (ID SM-003) modified by the application of the *Prądnik method*. Blue coloured area indicates the scar resulting from the *Prądnik spall* removal. – (Photo Michael Baales; Illustration Olaf Jöris [Jöris 1992]). – Scale 2:3.

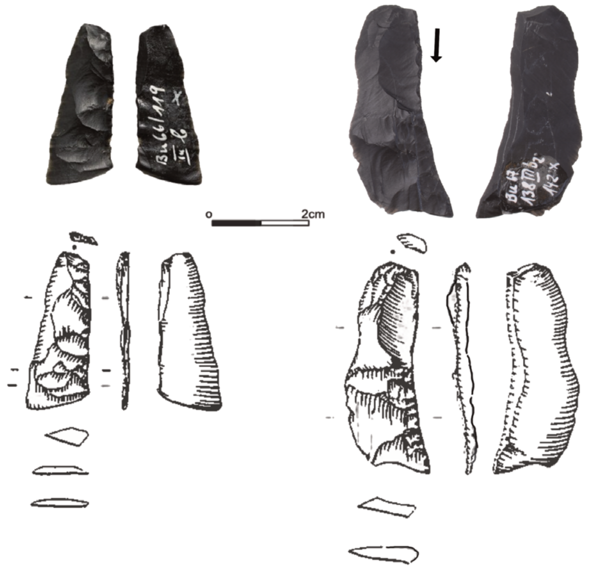

Fig. 5 *Prądnik spalls* from Buhlen (left ID BU-155, right ID BU-136). The artefact on the left side illustrates a primary, the on the right side a secondary *Prądnik spall*. The black arrow indicates the direction of the applied *Prądnik method*. – (Photo left Sabine Steidl, RGZM; Illustration Olaf Jöris [Jöris 2001]). – Scale 2:3.

or on the resulting »*Prądnik spalls*« (hereafter *Prądnik spall*) (**fig. 5**). Based on the pattern of scars on the dorsal face of the *Prądnik spalls* it is possible to distinguish primary from secondary removals (Jöris 2001).
The application of the *Prądnik method* results in a tool with a stable and straight active edge. At the same time, the lateral removal (re-)sharpens the tool by reducing the edge angle (Jöris 2006; Frick et al. 2017; Frick/Herkert 2019; Jöris/Uomini 2019; Frick 2020a). Reconstructions of the *chaînes opératoires* of *Keilmesser* placed the *Prądnick method* as a technological modification at the end of the manufacturing sequences (Jöris 2001; 2006; Frick et al. 2017; Frick/Herkert 2019). Hence, the removal of a *Prądnik spalls* can also been seen as tool finishing (Frick/Herkert 2019; Jöris/Uomini 2019). In this sense, another aspect should also be discussed: *Keilmesser*, in particular such pieces with a *Prądnik method* modification, display a two-parted active edge (double morphology). This horizontal separation in two parts becomes visible by the changing quality (in the sense of different retouch, different edge angle etc.) of the active edge, which puts a special emphasis on the distal part of the tool. Therefore, these tools seem to have been created as at least bi-functional tools (Jöris/Uomini 2019). The lower part with the larger edge angle is assumed to function thereby as a scraper or the like and the distal part with the smaller edge angle as a knife for cutting (Frick/Herkert 2019).

TOOL DESIGN

Artefacts, especially stone tools, do provide insights into human behaviour (Klein 2000; Odell 2000; Ambrose 2001; Lycett 2015; Dibble et al. 2017; Key/Proffitt/de la Torre 2020). Understanding the tool design can thereby provide information about early human technological and ecological adaptations. More importantly, it always reflects human behaviour in the sense of conscious or unconscious decision-making. One of these behaviour-related attributes reflected by the tools is the choice of raw material. This decision can be based on the availability, the size, the shape or even by the knappability. Also, the shape of a tool is

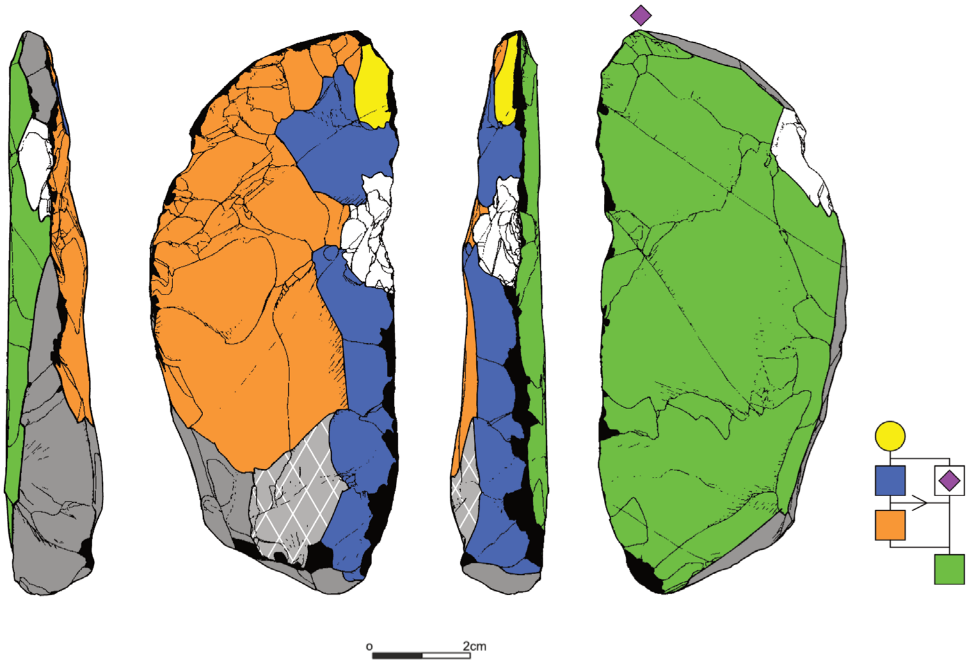

Fig. 6 *Keilmesser* from Buhlen (ID BU-163). The colours correlate with the Harris diagram on the right, indicating the order of individual retouch sequences from bottom to top. The yellow circle indicates the removal of a *Prądnik spall*, the purple diamond indicates the preparation of a striking platform. – (After Jöris/Uomini 2019). – Scale 2:3.

undeniably (and maybe even to a great extent) the result of human decision-making. While the choice of the raw material can probably be seen as the most obvious aspects concerning human behaviour (Dibble et al. 2017), there are other details in the tool design, for instance edge retouch or hafting, which can provide information (Kuhn 1994; Carr 1995).

Technology

Many *Keilmesser* assemblages are well studied from a technological and typological point of view. Considerable research on the tool production, curation and function has been done, resulting in assumptions, which are for the most part considered as valid **tab. 1**). It has been argued that *Keilmesser* are highly standardised tools (Jöris 1994; Richter 1997, Jöris 2001; 2012). The overall tool concept seems to be present from the first step of the tool production onwards (Jöris 2001; Migal/Urbaowski 2006; Jöris 2012). The earliest step thereby is the selection of the raw material based on the shape. Depending on the morphology of the raw material, the back of the tool often stays unworked or only slightly retouched. Therefore, it seems certain that the raw material shape was integrated in the desired tool morphology. Due to the well-understood *chaînes opératoire,* it is possible to reconstruct the sequences of surface flake removals, giving the impression of a pattern that was mostly followed (Jöris 1992; Richter 1997; Jöris 2001; Pastoors 2001; Jöris 2006; Migal/Urbanowski 2006; Jöris/Uomini 2019; **fig. 6**). Technological studies also suggest an intended long usage for *Keilmesser* with a great potential for repeated reduction and re-use (Jöris 2001; Pastoors 2001; Jöris 2006). Analyses highlight the presence of different phases of retouch by overlaying negatives, which could be seen as a resharpening process. The tool size is known to vary between approximately 3 cm and 14 cm maximum length. It has been argued that this difference in size is the result of long-term use (Richter 1997; Pastoors/Schäfer 1999; Jöris 2001; Pastoors 2001; Jöris 2006). At the same time, the tool shape in relation seems to change isometrically (Iovita 2010). This required the application of consistent produc-

techno-functional aspects	interpretation	evidence	references (examples)	test method
technological choices and strategies	raw-material piece as integrated into the overall tool concept	mostly made from consciously shape-selected blocks / pebbles	Jöris 2001; 2006; 2012; Frick/Floss 2017; Wiśniewski et al. 2020	**lithic analysis**: characterisation of the back
		natural or roughly worked back	Krukowski 1939; Wetzel 1958; Bosinski 1967; Jöris 2001; 2012	
	preferential use of the local raw-material	mostly made from one type of raw-material	Veil et al. 1994; Jöris 2001; 2006; 2012	**raw material properties characterisation**
	raw material and blank selection as a conscious choice due to shape	mainly core-tools		**lithic analysis**: blank selection
	standardised manufacturing	similar manufacturing stages	Richter 1997; Jöris 1994; 2001; 2006; 2012; Migal/Urbaowski 2006; Frick/Herkert 2019, Wiśniewski et al. 2020	**lithic analysis**: documentation of the *chaîne opératoire*
	underlying tool concept			**lithic analysis**: comparison between samples + inter-site comparison
general morphology	tool with only one active edge	tool asymmetry	Bosinski 1967; Veil et al. 1994; Jöris 2006; 2012	**quantification edge design**: comparison between back and active edge values
				use-wear analysis: do traces on the back exist?
	conscious tool design (e.g. designed for handling)	triangular or wedge-shaped cross section	Jöris 2001; Jöris/Uomini 2019; Frick/Herkert 2019	**use-wear analysis**: distribution of use-wear traces
		flatter lower and more curved upper surface	Bosinski 1967; Veil et al. 1994; Jöris 2006	**use-wear analysis**: do hafting traces exist? geometric morphometrics
active edge design	focus on active edge	mostly bifacially retouched	Bosinski 1969; Jöris 2001; 2012; Weiss et al. 2018; Weiss 2020	**lithic analysis**: documentation of edge retouch
				quantification edge design: comparison back and active edge values
	bipartite / bi-functional edge	changing morphology/ retouch along the edge	Jöris 2001; Frick et al. 2017; Frick/Herkert 2019; Jöris/Uomini 2019; Weiss 2020	**quantification edge design**: edge angle along the edge
				use-wear analysis: do the traces differ in the distal and proximal part of the active edge?
				controlled experiments: edge angle functionality

techno-functional aspects	interpretation	evidence	references (examples)	test method
shape diversity	different *Keilmesser* shapes exist as chronological sequence	variety of Keilmesser shapes	Bosinski 1967; 1969	**lithic analysis**: size independent comparison
	shape of initial raw material pieces and resharpening lead to different *Keilmesser* shapes		Jöris 2001; 2004; 2006	
lateralisation	proxy for handedness	left- or right-lateral retouch	Jöris/Uomini 2019	**use-wear analysis**: orientation use-wear traces
				quantitative use-wear analysis: parameters texture directionality
Prądnik method	tool finishing / tool (re-)sharpening	frequent application (with intensive preparation)	Jöris 1992; 1994; 2001; Frick et al. 2017; Frick/Herkert 2019	**use-wear analysis**: are the spalls free from use-wear traces?
				lithic analysis: documentation of the *chaîne opératoire*
	attempt to gain an elongated spall for further usage			**use-wear analysis**: are there any use-wear traces on the spalls apart from the former active edge?
resharpening and reworking	resharpening in respect to perimeter sections to retain their functions	isometrical size changes	Iovita 2010; Weiss et al. 2018	**lithic analysis**: measurements perimeter section
				lithic analysis: length-width ratio of the tools
	extended tool use	(multiple) application of *Prądnik method*	Jöris 2001, Frick et al. 2017; Frick/Herkert 2019; Jöris/Uomini 20019	**lithic analysis**: recording of the *Prądnik spall* removals and *Prądnik spalls*
				use-wear analysis: do traces indicate a fresh resharpening?
		secondary *Prądnik spalls*		**lithic analysis**: recording of *Prądnik spall* type
				use-wear analysis: are there use-wear traces on the *Prądnik spalls*?
		removal of the distal tip	Jöris 2001	**lithic analysis**: recording *Keilmesser* tips

Table 1 Summary of the main morpho- and techno-functional aspects concerning *Keilmesser*. The table also includes common interpretations and ideas how to address and test them. Methods highlighted in green have been applied in this project.

techno-functional aspects	interpretation	evidence	references (examples)	test method
tool biographies	long life-histories	negatives / scars on tools	Richter 1997; Pastoors/Schäfer 1999; Pastoors 2001; Jöris 2001; 2006	**controlled experiments**: when is re-sharpening needed? (tool durability)
				use-wear analysis: are there traces corresponding to long-term / intensive use?
				quantitative use-wear analysis: parameters areal surface texture
		numerous *Prądnik spalls*	Jöris 2001; Frick et al. 2017; Frick/Herkert 2019	**use-wear analysis**: are there use-wear traces on the *Prądnik spalls*?
function	tool suitable for cutting tasks	sharp tool edges	Jöris 2001; Frick et al. 2017; Frick/Herkert 2019; Jöris/Uomini 2019; Weiss 2020	**quantification edge design**
	multifunctional tool	changing morphology / retouch along the edge	Jöris 2001; 2006; 2012; 2014; Rots 2009; Golovanova et al. 2017; Frick/Herkert 2019	**quantification edge design**
				controlled experiments: testing tool performance based on edge angle

Table 1 (continued)

tion concepts and elaborated resharpening strategies. Changes in morphology due to modification (e.g. resharpening in the case of bifacial retouched tools) or recycling is widely accepted and has been argued repeatedly (Dibble 1995; Iovita 2009; 2010; 2014; Vaquero et al. 2015). Analysis of different Middle Palaeolithic assemblages such as Buhlen, Germany (Jöris 2001), Grotte de la Verpillière I and II, France (Frick 2016a; 2016b), and Ciemna Cave, Poland (Valde-Nowak et al. 2014; 2016) were able to demonstrate the entire *chaînes opératoire* of *Keilmesser* production, including rejuvenation processes.

Although the manufacture of *Keilmesser* follows an underlying tool concept and a high degree of standardisation, they often display a morphological diversity (**fig. 7**). In general, the outline shape of a *Keilmesser* can be separated in three distinct parts (perimeter characteristics). The first part defines the unworked or roughly thinned base, which merges into the back. The distal posterior part of the tool often forms an arch or a bow. The active edge is the third of these tool parts. The size and shape of these outline parts can vary, resulting in the morphological differentiation of different *Keilmesser* shapes. In literature, the *Keilmesser* shapes are named after well-known sites like »Königsaue-type *Keilmesser*« (Mania/Toepfer 1973), »Lichtenberger *Keilmesser*« (Veil et al. 1994), »Bockstein-« (Wetzel/Bosinski 1969), »*Prądnik*-« (Wetzel/Bosinski 1969) or »*Klausennische-Messer*« (Wetzel/Bosinski 1969) and »*Balver*« (Jöris 2001) or »*Buhlener Keilmesser*« (Jöris 2001). It is most likely that these various *Keilmesser* shapes reflect distinct stages in the reduction of a tool during its use and subsequent modification (Jöris 2001; Pastoors 2001; Jöris 2004; Migal/Urbanowski 2006). The reasons for this outline shape variability, is most likely due to reduction and reworking processes (Jöris 2001; Pastoors 2001; Jöris 2004; Migal/Urbanowski 2006; Weiss 2020).

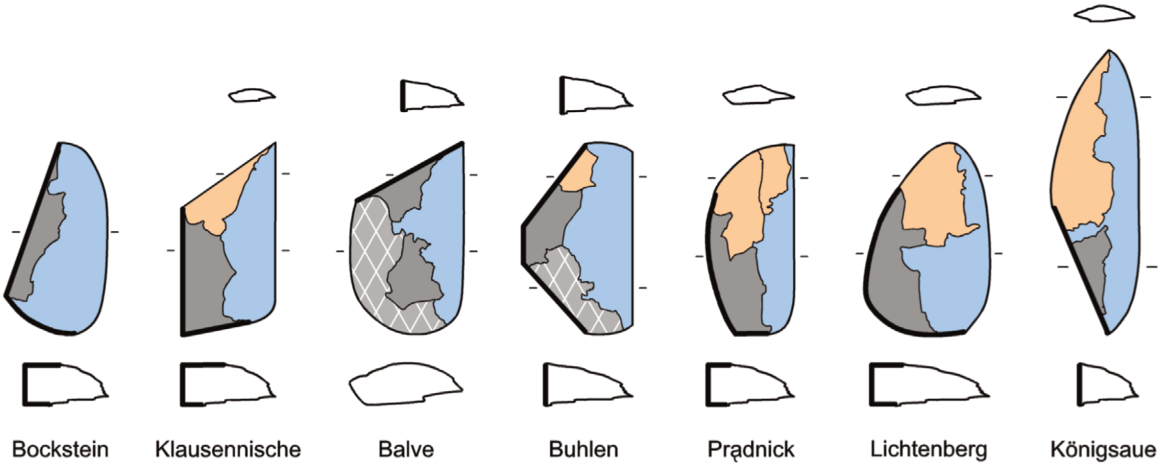

Fig. 7 Half-schematic illustration of the range of different shapes of *Keilmesser*. The thick black line indicates the back and the base as one perimeter section. The colours relate to unworked parts or thinning retouch orientated from the back and the base (grey), thinning of the distal posterior part (orange) and flat surface retouch of the active edge (light blue). – (After Jöris/Uomini 2019). – Not to scale.

An interesting aspect concerning long tool usage and reworking processes are distal *Keilmesser* fragments – here referred to as *Keilmesser* tips (**fig. 8**). The *Keilmesser* tips are sometimes part of *Keilmesser* inventories. An intentional removal of the distal part of the *Keilmesser* has been documented (Jöris 2001). This has been seen as a likely possibility to facilitate a longer tool use. Consequently, the tool's length is notably shorter, but the created fracture surface could serve as a new striking platform for a further thinning of the distal end. It is therefore probable that *Keilmesser* tips represent the reworking of one (worn out) *Keilmesser* shape into another.

The design of a tool is not only determined by the raw material used or the technology applied, but also directly influenced by the producer. Conversely, a tool can tell a lot about the individual who created it. This can be the handedness for instance. Some tools, as *Keilmesser* and *Prądnik scraper* can likely provide information about the handedness of the producer.

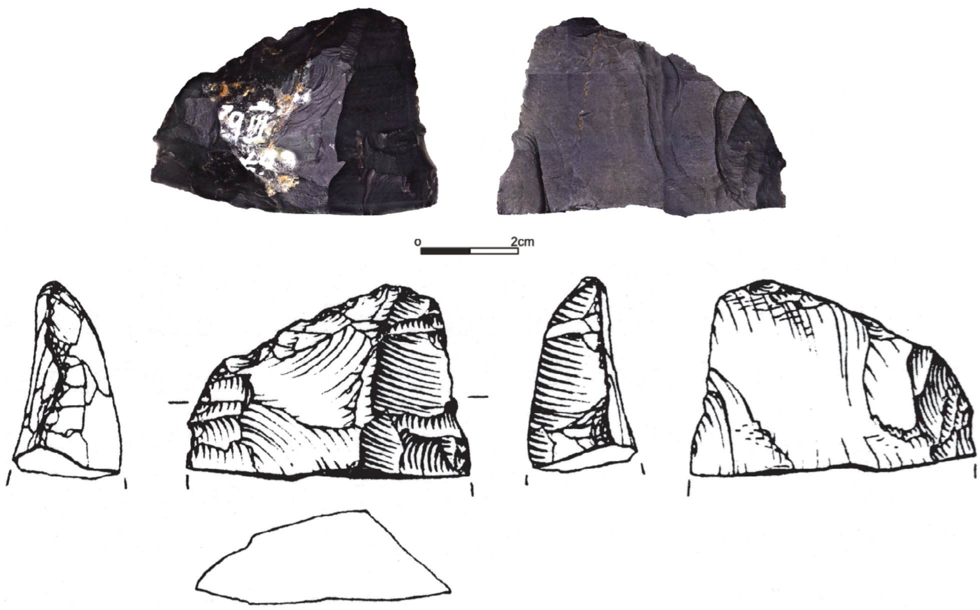

Fig. 8 *Keilmesser* tip from Buhlen (ID BU-086). – (Illustration Olaf Jöris [Jöris 2001]). – Scale 2:3.

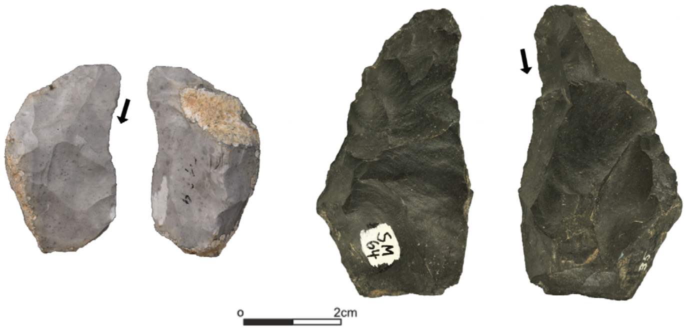

Fig. 9 Left-lateral *Keilmesser* (left) from Ramioul (ID R-002) and right-lateral *Keilmesser* (right) from Balver Höhle (ID MU-280). The black arrows indicate the direction of the applied *Prądnik method* visible as negative of the removal. – Scale 2:3.

Fig. 10 Top row: Primary left-lateral *Prądnik spall* (left) from Balver Höhle (ID MU-116) and primary right-lateral *Prądnik spall* (right) from Buhlen (ID BU-157). Bottom row: Secondary left-lateral *Prądnik spall* (left) from Balver Höhle (ID MU-307) and secondary right-lateral *Prądnik spall* (right) from Buhlen (ID BU-121). The black arrows indicate the direction of the applied *Prądnik method* visible as the negative of the removal. – (Photo Buhlen artefacts Sabine Steidl, RGZM). – Scale 1:1.

Based on the overall tool asymmetry, it is possible to distinguish left-lateral from right-lateral tools (Jöris / Uomini 2019; **fig. 9**). Moreover, this lateralisation can also be noticed regarding the *Prądnik spalls* (**fig. 10**). The implications resulting from the documented tool lateralisation are uncertain though. Arguments have been put forward which see the tool lateralisation as a proxy for human handedness (Cashmore / Uomini / Chapelain 2008; Uomini 2009). Since the production of a *Keilmesser* is rather complicated due to complex morphology and the asymmetry, each tool was probably produced by the intended user (Jöris / Uomini 2019). Unlike apes, humans have a species-level bias towards one hand preference (McGrew / Marchant 1997; Cashmore / Uomini / Chapelain 2008; Uomini 2009). Handedness, which, is closely related to brain lateralisation, has to be seen as a key feature of the motor-cognitive development from early human ancestors onwards (Uomini / Ruck 2018). It has been argued that the bias towards the preference of one hand is likely to increase in hominins when coupled with social learning (Morgan et al. 2015; Uomini / Lawson 2017; Uomini / Ruck 2018). Thus, together with the standards in tool design, the link between Middle Palaeolithic evidence for handedness and knowledge transfer in Neanderthals could likely be made.

Tool function and use

Tools are produced in a way to function. Some tools are manufactured for one function, some for multiple. Moreover, the function can change within the use-life of a tool. Design is thereby the key to function. In *Keilmesser*, the tool's morphology suggests that they could have been used for different activities, for example cutting, scraping and carving. Interpretations see *Keilmesser* as multifunctional or at least bi-functional tools (Jöris 2001; Rots 2009; Jöris 2006; 2012; Golovanova et al. 2017; Frick / Herkert 2019; **fig. 11**). This argumentation is based on tool morphology only and has not been verified through further analysis. The same counts for the tool handling. The morphology suggests a tool handling without additional hafting (Jöris 2001; Jöris / Uomini 2019).

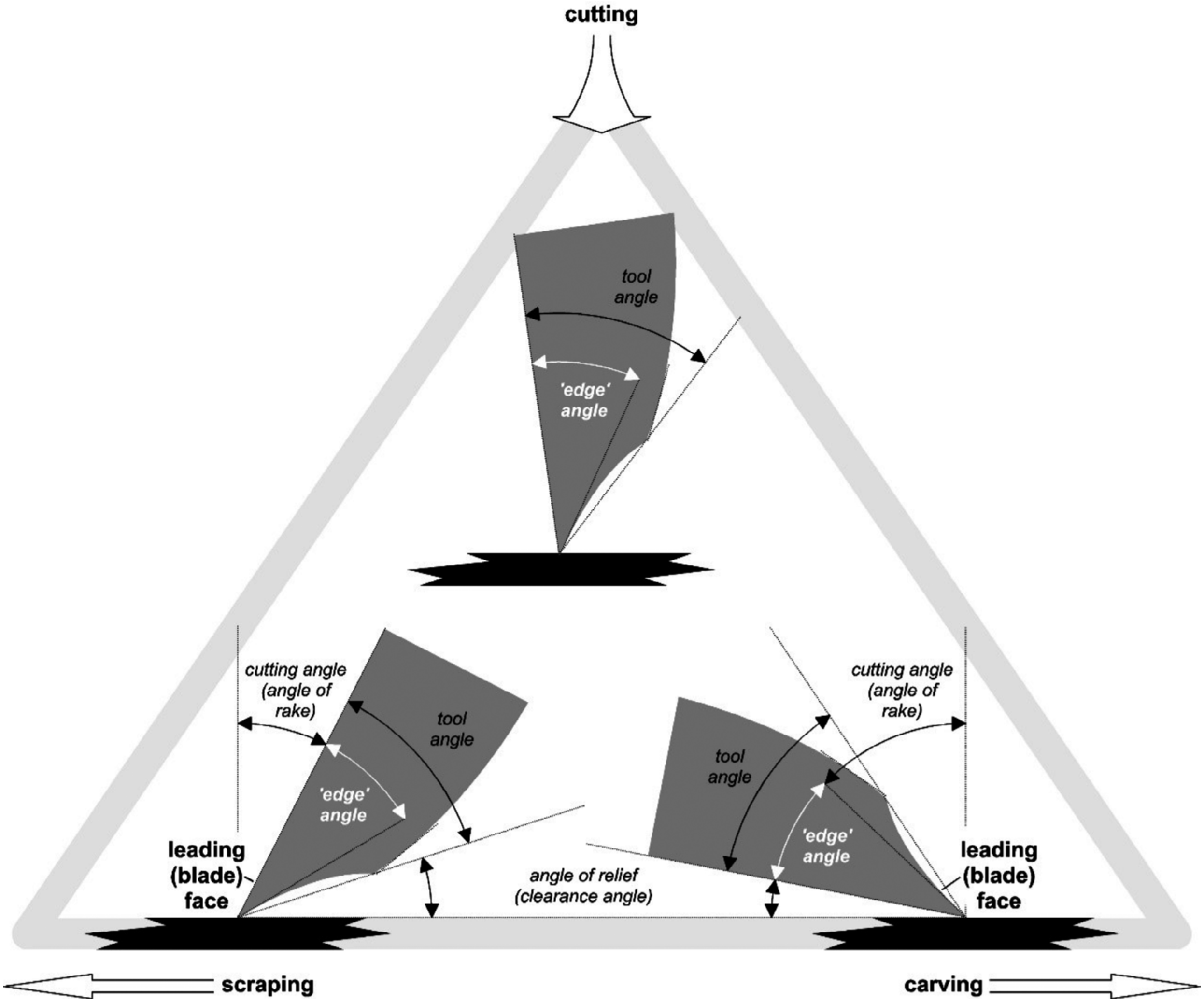

Fig. 11 Cross section of an idealised right-sided *Keilmesser* performing cutting, carving and scraping. Depending of the performed movement, the angle of relief has to be adapted. – (After Jöris/Uomini 2019).

Except from the morphological point of view, the function of *Keilmesser* and *Prądnik scrapers* has only been rarely addressed. Reports about use-wear analysis performed on *Keilmesser*, *Prądnik scrapers* or *Prądnik spalls* are almost absent. In one study, a large variety of tool uses was identified for *Keilmesser* (Rots 2009). Whether *Keilmesser* and *Prądnik* scrapers share not only technological attributes (Jöris 2001; 2004; Jöris/Uomini 2019) but also the function, has not been addressed yet. The aspect of tool function is also related to the observed long use-life histories of *Keilmesser*. Especially the interpretation of the *Prądnik method* for tool resharpening can be tested with use-wear analysis.

Although use-wear analysis provides the only way of finding direct evidence for tool use, not every aspect of tool use can be addressed with use-wear analysis solely. Also, aspects such as tool performance, durability and efficiency are relevant concerning tool function and use (Key/Lycett 2014; Key/Fisch/Eren 2018; Key/Lycett 2018). Thus, use-wear analysis ideally needs to be combined with controlled experiments. Since the aforementioned terms are critical for the understanding and the interpretation of results, their definition in the sense of tool use should be given:

Performance as a term implicates action in some kind. Performance describes how well a process or task was accomplished. While performance can be basically defined by the combination of the two aspects ef-

fectiveness and efficiency, effectiveness itself does not imply efficiency. Effectiveness (synonym to efficacy) is a measure that describes the relationship between a goal achievement and a defined goal. It therefore can also be described as a measure of effect. Efficiency defines the ratio between costs and benefits. In other words, it can be seen as an indicator of the consumed resources (e. g. energy, time) to achieve a goal. Durability is a measure of functionality over use. The term describes the ability of something (e. g. a physical product) to retain function. Loss of durability could be due to attrition from use or other factors that are not related to use such as age, natural decay etc. Durability excludes processes of maintenance or repair.
In the case of a controlled experiment with lithic samples the definitions could be transferred in the following sense: Performance would describe how the sample was able to conduct a task, e. g. cutting. This could be for instance reviewed by the cut (depth, quality etc.) the sample produced compared with the material loss on the sample itself (e. g. breakage). Effectiveness again could be assessed by the cut and its penetration depth etc. Efficiency can be addressed by aspects such as the applied force needed to perform the task or material loss on the sample itself and the ratio between these aspects and the achieved goal, in this instance the cut. Durability describes how often a task could be performed under the same condition before the sample was altered in a way that it could not function anymore as initially intended. For instance, the sample could be blunt or fractured. Durability in this sense excludes an adjustment of the given parameters (e. g. increasing the force) and tool maintenance.

SUMMARY

Due to the aforementioned characteristics, *Keilmesser* and *Prądnik scraper* provide a unique archive for tracing certain aspects of late Neanderthal behaviour. These may range from understanding tool function and its underlying design and production concept, technical innovations, learning strategies, the transmission of ideas and knowledge to the formation of late Neanderthal regional studies. Although these concepts are most often difficult to recognise over much of the Palaeolithic archaeological record, they gain visibility in the Late Middle Palaeolithic. In *Keilmesser*, long reduction sequences have repeatedly been documented. This allows for detailed morpho-technological reconstructions of the tool's use-life histories, including repetitive phases of production and tool maintenance, re-sharpening and re-use. Another focus has often been on the degree of tool standardisation. Technological studies could demonstrate the existence of similar working steps within the manufacture of *Keilmesser*. This implies an underlying tool concept with several production as well as reworking sequences. Which processes provoked Neanderthals to follow this level of tool standardisation remains speculative. Nevertheless, it raises the question of culturally transmitted tool-concepts. Related to this aspect are the implications that could be made from tool lateralisation. Tool lateralisation is likely to be interpreted as a proxy for handedness and would thus provide early evidence for human hand preference, social learning and knowledge transfer (Uomini/Ruck 2018; Jöris/Uomini 2019). The majority of *Keilmesser* assemblages are well studied from a technological and typological point of view. By contrast, use-wear analysis has rarely been done yet (Rots 2009). So far, only a small sample has been analysed, resulting in the identification of a large variety of tool uses. Many functional assumptions concerning the use of *Keilmesser* have been based on tool design and morphology according to archaeologists' interpretations and ethnographic observations. These interpretations ascribe *Keilmesser* a multifunctional purpose (Jöris 2001; 2006; Rots 2009; Jöris 2012; Golovanova et al. 2017, Frick/Herkert 2019). Other observations address the design and the modification of the active edge of *Keilmesser*. The mostly bifacially worked, acute active edge is frequently altered by an application of the *Prądnik method*. The implications of this modification can be assumed (Jöris 2001; Frick et al. 2017; Frick/Herkert 2019), but they have not been tested experimentally. In order to use such interpretations as baselines when inferring human behaviour, the interpretations have to be tested and validated.

To summarise, asymmetric tools such as *Keilmesser* and *Prądnik scrapers* from the Late Middle Palaeolithic serve as a perfect case study to investigate tool design as a bridge between technology, typology, tool function and individual impact from the producer.

AIMS

The aim behind this PhD project can be summarised in the following way: to test known interpretations and gain new information about asymmetric tools from the Late Middle Palaeolithic. *Keilmesser* as well as *Prądnik scrapers* thereby serve as a case study. The only way to do so is by applying and combining different methods in order to focus on these tools from all possible angles. Therefore, this project consequently addresses aspects such as technology, typology, tool use and tool function in combination.

To start with, a techno-typological analysis has to be carried out. As mentioned before, techno-typological analyses on *Keilmesser* have already been extensively conducted. These analyses resulted in numerous information about the lithics, providing a detailed picture. However, since techno-typological studies do have their limitations, as all studies do, some observations will not pass the stage of a hypothesis. Other methods or types of analysis are unavoidable in order to test these observations. Thus, a multidisciplinary approach has been chosen. This approach moves beyond conventional technological and typological lithic studies by also involving a study of material properties, use-wear analysis and controlled experiments. This way, generally accepted models regarding *Keilmesser* can be tested (**tab. 1**). In the following, central aspects concerning the tools will be listed. Likewise, the selected methods, which can help testing these aspects, will be addressed and explained.

The general aim is to capture information about the tool design. Next to the technological and typological analysis, 3D data turns out to beneficial in addition to this. High-resolution 3D data facilitate the possibility for further and precise measurements. Moreover, a more distinct, high resolution picture of the active edge of the *Keilmesser* and *Prądnik scrapers* can be obtained. This aspect is relevant, because it allows addressing several questions regarding *Keilmesser.* For example, the edge angle can be calculated in detail. In this way, the idea that a lower edge angle is more efficient than a higher one (especially for tasks such as cutting) can be taken up. Through a comparison, the angles calculated along all entire tool edges can be put in proportions. This will lead to a better understanding of the edge design. Furthermore, the effect of an edge modification through the *Prądnik method* can be analysed quantitatively.

A second aspect is the raw material. The tool design is usually influenced to a certain extent by the selected raw material. Measuring the raw material properties is thus an important component of the methodological approach. Next to the possible influence of the raw material on tool morphology, also the potential efficiency during the use-life of the tool can be evaluated. The two raw materials, mainly encountered in the studied assemblages, silicified schist and flint, serve as a comparison.

To interpret the meaning of *Keilmesser* in the variability of Middle Palaeolithic lithics, one of the most important questions concerns their usage. The only way of gaining direct evidence for tool use is by the performance of use-wear analysis, or more precisely qualitative and quantitative use-wear analysis. With this project, this method will be applied for the first time to a large series of artefacts related to asymmetric tool production and use. This approach is relevant for several reasons. The first and most obvious one is the identification of tool use. The given interpretation of *Keilmesser* as multifunctional tools can be tested. The documentation of the location and the orientation of the use-wear traces is a second objective of the use-wear analysis. The location is important to address aspects such as tool handling, also in the sense of potential tool hafting, and again, to understand overall tool design. The distribution in combination with the orientation of the traces can offer new information about the potential left- or right-handedness of the tool user. Furthermore, use-wear analysis of the *Prądnik spalls* can reveal the answer to the questions if the *Prądnik method* was applied to sharpen the tool edge or as a last finishing step within the tool manufacturing process. The latter would be disproven by the presence of use-wear traces on the dorsal surface of primary *Prądnik spalls*. Use-wear analyses are also likely to contribute on revealing the relationship between *Keilmesser* and *Prądnik scraper*. The tools share technological attributes, but it is unclear if the same counts for their function.

Another methodological approach with the purpose of gaining new data and testing interpretations is given by the conduction of controlled experiments. With the so-called *second generation experiments* (Eren et al. 2016; Lin/Režek/Dibble 2018; *sensu* Marreiros et al. 2020), different aspects regarding tool use and tool performance can be addressed by the use of a mechanical devise. Samples prepared with edge angles derived from the measurements taken from the *Keilmesser* assemblages will be used for the experiments. In this way, their ability to perform different tasks – cutting, carving and scraping – can be tested. The suitability for certain edge angles during these movements can be examined. The approach is meant to test the possible (multi-) functionality of the tool. At the same time, using controlled experiments allow to assess tool performance, efficiency and durability. Questions regarding the behaviour of the two involved raw materials as well as an alteration of the edge angle during the tool use can be raised. In general, *second generation experiments* offer the possibility to test and understand the cause-effect relations of the involved variables (e. g. edge angle, raw material). The results of the experiments can lead to an understanding of when for example re-sharpening is necessary to keep the tool efficient. This approach brings the functional inferences from the experimental setup together with independent data obtained from the archaeological artefacts. Simultaneously, the conduction of the experiments is beneficial in terms of contributing to a use-wear traces reference collection.

To summarise, the employment of several approaches aims at gaining new information about the techno-typological and the morpho-functional tool use of *Keilmesser*. This multidisciplinary approach can be condensed under the umbrella term of a functional analysis (*sensu* Marreiros et al. 2020). Functional analysis consists of technological, typological and use-wear studies. At the same time, and especially in the case of this project, experiments are a significant part of it. While use-wear analysis will contribute to an understanding of the actual tool use, experiments are indispensable to address the relationship between the morphological design of *Keilmesser* and their functionality. This proposed approach aims at providing new data to test the given interpretations of *Keilmesser*. Taken together, the only way to gain a more holistic view on *Keilmesser* is a multidisciplinary approach. The combination of the different scales of analysis and methods as techno-typological and material properties studies, use-wear analysis and controlled experiments is conditional upon understanding the concepts underlying tool design, function and its realisation. Linked in coherence with these topics are aspects such as learning strategies, the transmission of ideas and knowledge about the formation of late Neanderthal rules and regulations. Thus, this case study will lead to an improved understanding of Late Middle Palaeolithic technological adaptability and in context, will throw light on Neanderthal behavioural choices. Although human behaviour is multifaceted and complex, every piece of a puzzle should be a desirable contribution.